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The Domanik Formation of the Timan–Pechora Basin: Radiolarians, Biostratigraphy, and Sedimentation Conditions

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Received March 4, 1999

Abstract—A diverse radiolarian assemblage of 127 species was studied for the first time from the middle Frasnian Domanik Formation of the Timan–Pechora province. The availability of sponge spicules, acritarchs, and rhizomorphs is proved. After a detailed analysis of macerated radiolarians, three subassemblages (lower Rdm-1, middle Rdm-2, upper Rdm-3) of substantially different quantitative and qualitative composition were distinguished in the *Moskovistella allbororum–Ceratoikiscum ukhtensis* radiolarian assemblage. Echinate species of Aculearia prevail over spherical Sphaerellaria forms, and this suggests a relatively cold conditions in bottom water mass. Cyclically changing taphocoenoses testify to significant ecological rearrangements during the Domanik time. A new interpretation of depositional conditions for Domanik Formation sediments in the southern Timan–Pechora basin of Russia is presented.

Key words: Domanik, Domanik Formation, middle Frasnian, radiolarians, biostratigraphy, sedimentation conditions, taphocoenoses.

Deposits of the Domanik Formation, the mother beds for oil, are indicators of specific paleogeographic conditions in the past sedimentation basin. The term "Domanik" means a sequence of alternating bituminous–calcareous and combustible shale interlayers. The sequence is characterized by a specific complex of organic remains. At present, terms "Domanik" and "domanikit" are denote not only deposits of the middle Frasnian Domanik Formation, but also rocks of the "Domanik" habit, which vary in age and show C_{org} content ranging from 2.5 to 10–40% (Vassoevich, 1972). Distinctive features of Domanik deposits are: (1) a high content of organic substance;[1] (2) characteristic lithological facies; (3) peculiar assemblages of planktonic organisms; and (4) the absence of normal-sea benthos.

The Domanik deposits attracted attention of geologists for more than 300 years. As early as in the 17th century, the Ukhta oil and Domanik combustible shales were familiar to Peter the Great, and their samples were sent to Holland for investigation in 1697. The Domanik was first mentioned in scientific literature by Nikolai Witsen, an employee of the Holland Embassy in Russia (Witsen, 1692). He pointed out in 1692 that oil was emitted from water of the Ukhta River 1.5 mile away from the portage (carrying place between two navigable waters), and that "Domanik" from the same place burns like a candle. In 1745, Fedor Pryadunov commenced the oil recovery at the Ukhta River and pioneered in building a small oil refinery. In 1855, the first 50-m-deep well, which then was considered as deep, was drilled in this area (Fishman, 1991; Kuznetsov, 1995).

A. von Keyserling was first to describe and characterize the Domanik deposits of the Ukhta region in the middle of 19th century after his visit to the Pechora territory (Tikhomirov, 1960). In his first account from that expedition, Keyserling reported in particular that he revealed beds transitional from the Silurian to Devonian, which are exposed along the Syas' River banks, being unknown in westerly sections (Keyserling, 1843). In 1843, he established that so-called "Domanik" (clay-marly bituminous shale saturated with oil and bearing goniatites and other fauna) is an oil-bearing rock. Keyserling attributed the Domanik deposits to the Lower Devonian–Silurian, considering them as oldest rocks of the Ukhta River basin. After the laboratory study of materials collected in the field, Keyserling and Krusenshteyn (1846) published a fundamental work full of materials characterizing geology and geography of the vast and poorly studied Pechora region. They reported that the Timan Range is mainly composed of Devonian and Carboniferous deposits and extends northwestwards, being separated from the Urals by a vast territory of Bol'shezemel'skaya Tundra covered by Quaternary deposits. The geological part of the work was fully included as an independent section into the joint work by Murchison, Verneuil, and Keyserling (1845) on the geology of the European Russia. For about 100 years, the map compiled by Keyserling and

[1] The problem of a hydrocarbon source for oil-and-gas deposits and role of radiolarians in the formation of hydrocarbon potential of oil-bearing rocks have been considered by Afanasieva and Mikhailova (1998) and by Afanasieva (2000a, 2000b).

Krusenshteyn was the only source for geological reconstructions.

Since the latest 19th century, general geological (paleontological–stratigraphic and tectonic) aspects of Domanik deposits received a considerable attention of geoscientists. Investigations of Domanik deposits in the Ukhta River basin were mostly connected with oil prospecting and included geological survey of corresponding localities, characterization of principal faunal groups, and mapping of oil and gas showings (Kuznetsov, 1995). An appreciable contribution to investigation of the Ukhta region was made by the Timan Expedition of 1889 that was headed by Academician F.N. Chernyshev who scientifically substantiated the viewpoint that the Ukhta region is an area promising for oil (Chernyshev, 1890). Devonian deposits in the Ukhta River basin were thereafter studied by Kalitskii and Stoyanov (1919, 1921). They distinguished six geographical zones of Devonian deposits and estimated the full thickness of 74.4 m for Domanik deposits in the Ukhta region. The problems of the Domanik deposits were touched upon in a series of works by Tikhonovich (1930, 1941), Tikhomirov (1948, 1967, 1972, 1994, 1995), Kushnareva (1959, 1963, 1972, 1978), Zav'yalov (1966), and Maksimova (1970). Abundant radiolarians found in the stratotype section of the Domanik Formation were mentioned for the first time by Kushnareva as early as in 1959. The first pictures of radiolarians from the formation (without identification and description) were published by Maksimova (1970, Table 5).[2]

Drilling for oil and gas that was initiated in the Timan–Pechora province in the 1970s revealed the oil and gas influx from Paleozoic deposits and gave a voluminous material for studying the Domanik Formation phenomenon. Devonian deposits of the Ukhta River basin were studied by A.I. Lyashenko, Z.I. Tsayu, V.S. Yudin, N.F. Ivanov, N.A. Fokin, Yu.A. Yudina, M.N. Moskalenko, B.P. Bogdanov (see in Yudina and Moskalenko, 1994). At present, the study on Domanik deposits develops on several lines: paleontology and stratigraphy, lithology and geochemistry, paleogeography and oil prospecting. These are works by Menner *et al.* (1992, 1995), House *et al.* (in press), Belyaeva *et al.* (1992), Vishnevskaya *et al.* (1993), Tel'nova (1995), Kuz'min *et al.* (1997), and by other researchers. The comprehensive study of radiolarians from carbonate concretions occurring in siliceous rock varieties is of prime interest in this aspect (Afanasieva, 1994, 1996–2000; Afanasieva and Mikhailova, 1994, 1995).

MATERIAL

The region under consideration is located in the European north of Russia, in the southern Timan–Pechora oil-and-gas province (OGP) in close proximity to the town of Ukhta (Fig. 1). This is a stratotype area of the Domanik Formation corresponding in age to the middle Frasnian. The formation is up 59–69 m thick in the Ukhta region.

In total, 116 samples with radiolarians, 85 lithological samples, and 260 thin sections of different rock types from the Domanik Formation were selected for this study from core sections of four boreholes drilled at the following sites of the Timan–Pechora OGP: Shuda-Yag-1002 (depth interval of 66.6–86.5 m), Shuda-Yag-1003 (depth interval of 68.9–120.0 m), Ukhta-3B (depth interval of 63.7–118.5 m), and Vapovskaya-2056 (depth range of 72.0 m). In addition, 79 lithological samples and 106 thin sections characterizing 21 natural exposures along banks of the Ukhta, Domanik, Lyaiol, and Chut rivers were investigated.

Radiolarians, acritarchs, and sponge spicules were macerated using a standard method of chemical decomposition of rock samples in 10 to 15% solution of acetic acid and studied under the scanning electron microscope JSM-35CF within the magnification range of 150–3000 times. Lithological thin sections with radiolarians were studied under the polarizing microscope, magnification by 100 times.

LITHOLOGY AND STRATIGRAPHY

The Domanik Formation was distinguished by Tikhonovich (1930) who studied outcrops of the Ukhta River banks beginning from the Shuda-Yag Settlement to the Yarega River (Fig. 1). The composite section of the Domanik Formation spanning the middle Frasnian interval in the Timan–Pechora province was compiled earlier, mainly on data obtained from natural exposures. The lower part of the section is most completely exposed in the Chut' River lower reaches, whereas the middle and upper parts are best studied along banks of the Ukhta and Domanik rivers (near the Shuda-Yag settlement) (Fig. 1). These natural outcrops do not exhibit however the complete Domanik succession and some specific rocks varieties. Hence, in order to characterize the whole succession, we suggest to consider here a complete stratotype section of the Domanik Formation that was penetrated by boreholes in the vicinity of Ukhta and correlated with rocks previously described in outcrops (Menner *et al.*, 1992; House *et al.*, in press). The section is 59–69 m thick and clearly divisible into three members (Table 1). Lithological characteristics of the Domanik Formation are described using the borehole section Shuda-Yag-1003 as an example (Fig. 2).

Lower Member is represented by a sequence of dark gray limestone and cherty limestone beds alternating with siliciliths and the so-called combustible shales enclosing lenses of dark gray to black cherts and siliceous–calcareous concretions. The lower boundary of the member is established along a thin intercalation of

[2] The history of studying Frasnian radiolarians is presented in the work by Afanasieva and Aitchison (2001).

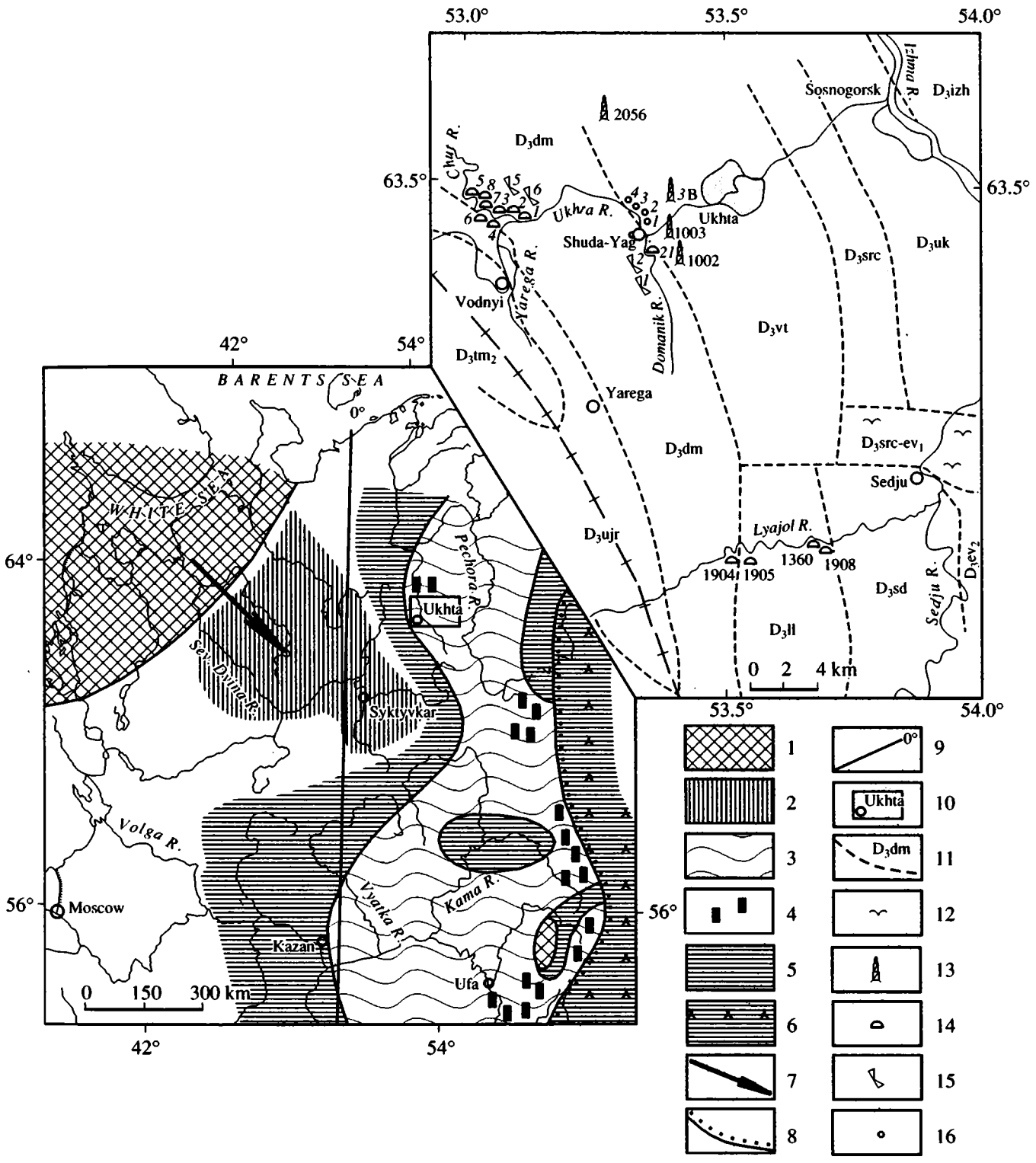


Fig. 1. Paleogeographic sketch map for the Russian platform of the Domanik time (modified after Maksimova, 1970): (1) land; (2) areas free from deposits due to subsequent washout; (3) Domanik deposits; (4) cherty lenses and intercalations in Domanik deposits; (5) marine deposits of non-Domanik type; (6) zone of underwater transportation; (7) direction of detritus transportation; (8) platform boundary; (9) paleoequator; (10) study area; (11) geological boundaries between the Verkhnii Timan (D_3tm_2) and the Ust-Yarega (D_3ujr) formations lower Frasnian; the Domanik Formation (D_3dm) of the middle Frasnian; the Vetlasyan (D_3vt), Sirachoi (D_3src), Sirachoi–Nizhnii Evlanov (D_3src-evl), Verkhnii Evlanov (D_3ev_2), Ukhta (D_3uk), Lyajol (D_3ll) and Sedju (D_3sd) formations of the upper Frasnian; the Izhma formation (D_3izh) of the Famennian; (12) paleoreefs; (13) boreholes; (14) exposures; (15) quarries; (16) sampling sites.

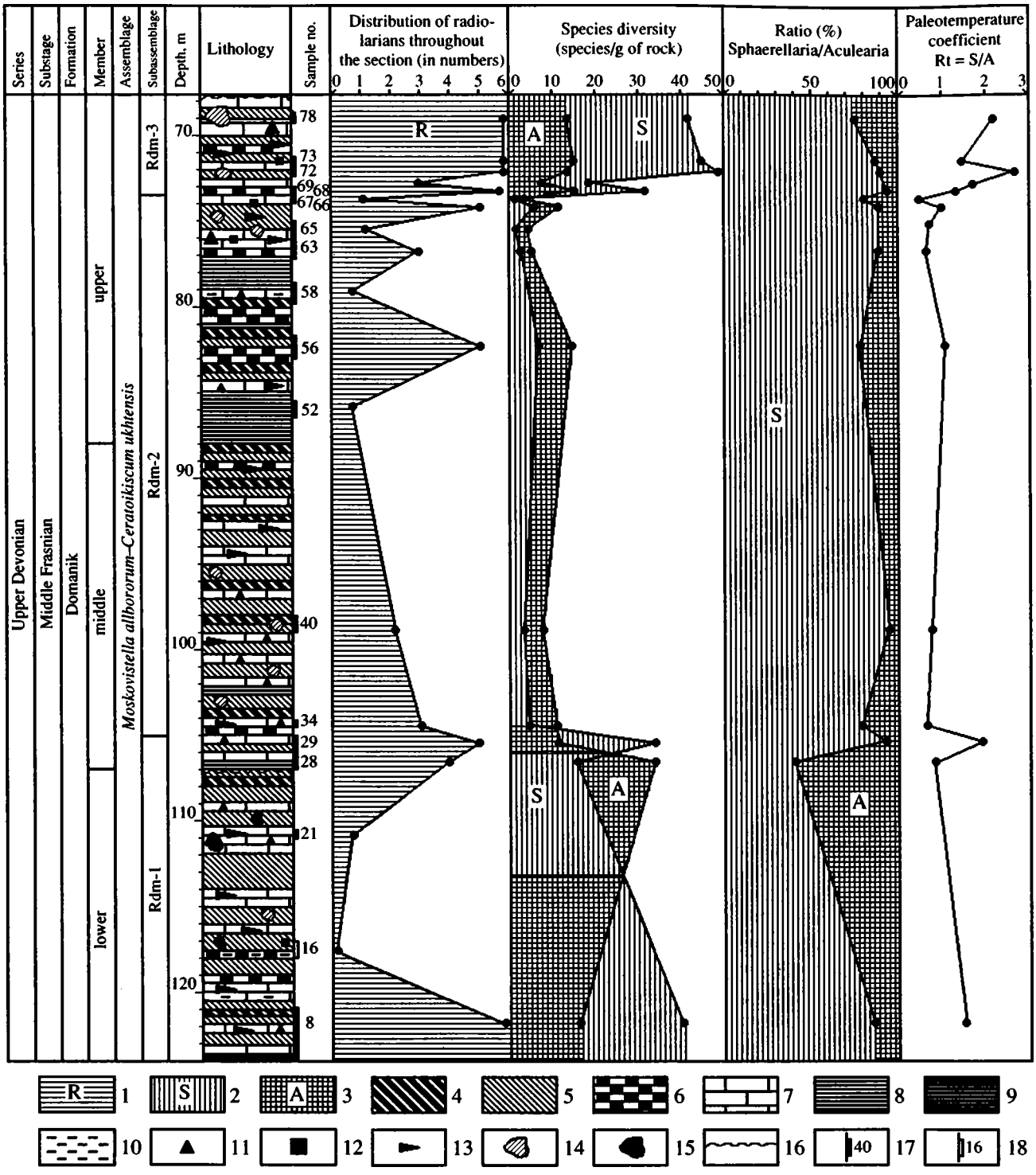


Fig. 2. Distribution of radiolarians throughout the section of Borehole Shuda-Yag-1003, the Timan–Pechora Province (stratotype of the *Moskovistella allbororum–Ceratoikiscum ukhtensis* radiolarian assemblage): (1) Radiolaria; (2) Sphaerellaria; (3) Aculearia; (4) chert; (5) silicified shale; (6) cherty limestone; (7) limestone; (8) clay; (9) mudstone; (10) claying; (11) silicification; (12) pyrite; (13) bituminosity; (14) calcareous concretions; (15) siliceous concretions; (16) unconformable boundary; (17) number of sample with radiolarians; (18) number of sample without radiolarians. Abundance of radiolarians (specimens/g of rock): 0, absent; 1, single (1–5); 2, rare (10–15); 3, few (20–40); 4, common (50–100); 5, frequent (200–500); 6, abundant (>1000).

Table 1. Correlation of the middle Frasnian deposits of the Domanik Formation

Formation	Member	Unit	Ukhta area (depth in m)			Radiolarian subassemblages	Shuda–Yag area (depth in m)			Radiolarian subassemblages
			BH 1B	BH 3B			BH 1002	BH 1003		
Domanik	Upper	4	54	57	57 70.4	Rdm-3	66	68	68 73.5	Rdm-3
		3								
		2								
		1	76	81		Rdm-2	88	88		Rdm-2
	Middle				98.7				105	
			99	99			106	107		
	Lower					Rdm-1				Rdm-1
			121	121	121		128	124	124	

greenish gray mudstone. The thickness of the member is 22–24 m (Fig. 2; Table 1).

Cherty limestones, bituminous clay–carbonate–cherty interlayers and siliciliths of the lower member are less abundant (30–35%) than other rocks (Zav'yalov, 1966; Maksimova, 1970). The rocks show syngenetic dispersed silicification and a high grade of early diagenetic transformations. Carbonate beds of the lower member are composed of whole-shell, polydetrital, micro-grained detritus-bearing, and tentaculitid limestones. Of particular interest are three massive limestone beds rich in shells of ammonoids, nautiloid orthocones, tentaculites, buchiolas, and gastropods associated with fish remains. Sponge spicules, Tentaculita, Radiolaria, Acritarcha are common in the unit; rhizocretions are also found there. Ammonoids identified in the lower Domanik member are *Probeloceras domanicense* (Holzapfel), *P. keyserlingi* (Holzapfel), *Ponticeras auritum* (Holzapfel), *P. bisulcatum* (Keyserling), *P. lebedeffi* (Holzapfel), *P. regale* House, *P.* cf. *tschernyschewi* (Holzapfel), *P. uchtense* (Keyserling), *Manticoceras ammon* (Keyserling), *M. sinuosum* (Hall), *Uchtites syrjanicus* (Holzapfel), *Tornoceras typum* (G. et F. Clarke); conodonts *Ancyrodella gigas* Young., *Mesotaxis asymmetricus* (Bischoff et Ziegler), *M. falsiovalis* Sandberg, Ziegler et Bultynk, *M. bogoslovskyi* Ovnatanova et Kuzmin, *Palmatolepsis transitans* Müller, *P. punctata* (Sandberger), *Domanikoceras timidum* Becker et Holzapfel, *Acanthoclymenia* cf. *genundewa* (Hinde), *Polygnathus timanicus* Ovnatanova, *P. dubius* Hinde, *P. vialovi* Zvereva; brachiopods *Lingula laewinsoni* Wen.; bivalves *Pterochaenia cashague* Clarke, *Buchiola retrostriata* (Buch), *B. snjatkowi* Zam., *Ontaria elegans* Zam.[3]

According to A.O. Ivanov, ichthyofauna of the Domanik Formation is represented by forms typical of the deep shelf. The lower member is rich in various placoderms and palaeoniscids, whereas remains of acanthodians and cartilaginous fishes are rare (Kuz'min *et al.*, 1997).

Middle Member is more siliceous. It is represented by flaggy cherty limestones, siliciliths, foliated rocks bituminous–clayey–calcareous–siliceous composition, and limestones, which enclose few thin (0.1–1.0 m) interbeds of clay in the lower part of the member. The lower boundary of the member is established at the base of a thin (0.3–1.5 m) reference bed of bluish gray clay, that is well traceable in exposures and borehole sections. The thickness of the member is 17–22 m (Fig. 2; Table 1).

Dominant rocks of the member (60–70%) are phthanites and cherty, silicified and fine-grained limestone with radiolarians, acritarchs, and sponge spicules. Abundant radiolarian remains, often calcitized and pyritized in places, are detected in thin sections of rock samples showing a fine alternation of siliceous and cal-

[3] Various fauna remains from the Domanik Formation of the Ukhta region were in different periods identified by paleontologists A.I. Lyashenko, M.I. Nefedova, Yu.A. Yudina, and M.A. Rzhonsnitskaya (Brachiopoda); by G.P. Martynova, E.N. Polenova, V.G. Egorov, N.A. Fokin, and M.N. Moskalenko (Ostracoda); by G.P. Lyashenko (Tentaculita); by V.F. Kulikova (Bivalvia); by B.I. Bogoslovskii and S.V. Yatskov (Ammonoidea); by V.G. Khalymbadzha, N.S. Ovnatanova, A.V. Kuz'min, and L.I. Mel'nikova (Conodonta); by A.A. Lyarskaya and A.O. Ivanov (ichthyofauna) (see in Yudina and Moskalenko, 1994; Menner *et al.*, 1992; House *et al.*, in press.

careous, highly bituminous laminae. Radiolarian-rich siliceous laminae are very thin (0.5–1.5 cm) and usually alternate with pelitomorphic siliceous rocks. In general, as compared to other members of the section, the middle member is poor in fossils, which are confined to individual interlayers, small in size and have very thin walls.

The middle and upper units of the member yield buchiolas, nautiloid orthocones, and ammonoid *Nordiceras timanicum* (Holzapfel), *Manticoceras ammon* (Keyserling), *M. lamet* (G. et Sandberger), *Tornoceras typum* (G. et F. Sandberger), *Phoenexites keyserlingi* (Müller), *Aulatornoceras* sp., *Lobotornoceras ? termierorum* (Clausen). Skeleton remains of lingulids, Tentaculita, sponge spicules, and algae are less frequent than in the lower and, especially, upper units of the sections. At the same time, abundant ostracodes *Entomozoe (Richteria) distincta* Pol. and remains of *Palmatolepis spinatus* Ovnatanova et Kuzmin are found in this unit only.

Upper Member is subdivided into four subunits (House *et al.*, in press) composed (from the base upward) of the following rocks: (1) greenish-gray to gray clays (up to 3–4 m thick); (2) flaggy cherty limestones alternating with limestone, combustible shale, and rare clay lamina (up to 6 m thick); (3) gray to dark gray clays with limestone interlayers in the upper part (up to 4.5 m thick); (4) dark gray thin-laminated cherty limestones and combustible shales with calcareous nodules (up to 8 m thick). The lower boundary of the member is established at the base of the lower clay unit. The thickness of the member is 20–23 m (Fig. 2; Table 1).

In its upper part, the upper member of the Domanik Formation is characterized by a high diversity of organic remains, Radiolaria, Acritarcha, and sponge spicules included. In places, mass remains of Tentaculita form oriented accumulations along bedding planes of bituminous clayey–siliceous–calcareous rocks and occur as individualized interlayers of tentaculitid limestone.

Conodonts identified in the upper Domanik member are *Palmatolepis punctata* (Hinde), *P. primus* (Ji), *P. hassi* Müller, *P. domanicense* Ovnatanova, *P. proversa* Ziegler, *P. ljaschenkoae* Ovnatanova, *P. mukronata* Klapper, Kuzmin et Ovnatanova, *P. amplificata* Klapper, Kuzmin et Ovnatanova, *P. orbicularis* Ovnatanova et Kuzmin, and *P. ormistoni* Klapper, Kuzmin et Ovnatanova.

According to A.O. Ivanov, abundance of cartilaginous and acanthodian fish remains gradually increases upward in the section of the Domanik Formation, whereas the total amount of placoderms decreases in this direction. In addition, rare remains of tassel-finned fishes were found at the top of the formation (Kuz'min *et al.*, 1997).

RADIOLARIANS

The comprehensive study of radiolarians collected from borehole sections and natural exposures in the Ukhta region of the Timan–Pechora paleobasin (Figs. 1, 2) is used to characterize the complete section of the Domanik Formation (the middle Frasnian). As is established, the radiolarian assemblage is very diverse, comprising 127 species and 35 genera, among which 8 genera and 55 species are new.[4] These unique organisms that represented source of organic substance for oil are studied in detail and used for reconstruction of specific sedimentation conditions in the basins favorable for concentration of organic matter. They offer as well a possibility to elaborate a new classification of Paleozoic radiolarians, to establish the detailed biostratigraphy of strata bearing oil and gas, and to characterize the *Moskovistella allbororum–Ceratoikiscum ukhtensis* radiolarian assemblage of the middle Frasnian Domanik Formation. The latter is divided into three subassemblages (lower Rdm-1, middle Rdm-2, and upper Rdm-3) substantially different in abundance of radiolarians and their composition (Afanasieva, 1994, 1996, 1997, 1998, 1999, 2000a, 2000b, 2000c, 2000d; Afanasieva and Mikhailova, 1994, 1995, 1995, 1996, 1998, 2000). The section of the Borehole Shuda-Yag-1003 described here (Fig. 2) represents stratotype of the *Moskovistella allbororum–Ceratoikiscum ukhtensis* Zone that yielded 109 radiolarian species.

The Rdm-1 subassemblage is mainly confined to limestone and cherty limestone of the lower member of the Domanik Formation (Fig. 2; Table 1). Its range (Table 2) corresponds to the ammonite *Ponticeras domanicense* Zone coupled with a lower parts of the *Nordiceras timanicum* Zone and to the conodont *Palmatolepis punctata* Zone coupled with the lower part of the *Palmatolepis hassi* Zone (Becker *et al.*, 1993; House *et al.*, in press).

Radiolarians of the Rdm-1 subassemblage are not abundant (from 100 to 1000 specimens per 1 g of rock). The subassemblage is characterized by a low species diversity of spherical Sphaerellaria forms (up to 42 species) and by a high content (up to 61%) of near-bottom echinate Aculearia forms representing 23 species, which play a noticeable role in the paleocoenosis (Fig. 2; Tables 3, 4).

Typical species of the Rdm-1 subassemblage (Table 2) are *Astroentactinia vishnevskayae* Afanasieva and *Nazarovites aprelevkensis* Afanasieva mostly widespread near the base of the Domanik Formation (Plate I; figs. 1, 18), *Russirad kazintsovae* Afanasieva (Plate I; fig. 9) that appears for the first time at this level, and *Ceratoikiscum* ? cf. *vimenum* Nazarov et Ormiston (Plate I; fig. 15) that has been described for the first time from lower Frasnian deposits of the Gogo Forma-

[4] Description of new radiolarian taxa is published in works by Afanasieva (2000b, 2000c, 2000d).

Table 2. Correlation of biostratigraphic zonal schemes of the Domanik stratotype (the middle Frasnian, the Domanik Formation)

Series	Substage	Formation	Member	House M.R., Menner V.V., Ovnatanova N.S. *et al.*, in press				M.S. Afanasieva, 1997, 2000			
				ammonoidea Zones		Standard Conodont Zonation		Radiolaria			
						actual	previous	Assemblage		Subassemblage	
Upper Devonian	middle Frasnian	Domanik	upper		H	*Palmatolepis rhenana* Early	*Palmatolepis gigas* Lower	*Moskovistella allbororum – Ceratoikiscum ukhtensis*	*Bientactinosphaera morozovi, Borisella bykovae, Ceratoikiscum ukhtensis, Moskovistella khaini, M.allbororum, M.victorialis, Nazarovites bioculus, Ornatoentactinia solita, Polyentactinia zhamoidai, Radiobisphaera menneri, Spongentactinella olafi*	Rdm-3	*Astroentactinia rusaevi, A. paronae, Bientactinosphaera guangxiensis, B. miletenkoi, Borisella maksimovae, B. mariae, Entactinia micula, Haplentactinia alekseevi, H. barskovi, Moskovistella rozanovi, Nazarovites pinnula, Ornatoentactinia spartaci, Palaeothalomnus arrhinia, P.timokhini, Radiobisphaera assidera*
						Palmatolepis jamieae	*Ancyrognathus triangularis*				
			middle	*Nordiceras timanicum*	G	*Palmatolepis hassi* Late				Rdm-2	*Entactinia bifida, Moskovistella mira*
							unzoned				
			lower	*Ponticeras domanicense*	F	Early	Upper			Rdm-1	*Astroentactinia tantilla, A. vishnevskayae, Ceratoikiscum avimexpectans, Entactinia bogdanovi, Helioentactinia gudymovae, Nazarovites aprelevkensis, N. mikhailovae, Palaeoscenidium scaurum, P. tabernaculum, Russirad kazintsovae*
					E		*Mesotaxis asymmetricus*				
					D	*Palmatolepis punctata*	Middle				

Table 3. Distribution of Sphaerellaria species in the section of Borehole Shuda-Yag-1003

Interval, m	120.9–124.0	106.0–107.0	105.0–106.0	104.1–104.6	98.0–99.0	81.6–83.0	75.0–77.3		73.5–74.0	73.3–73.5		73.0–73.3	71.9–72.4	71.4–71.9	68.9–69.3
Sample number	8	28	29	34	40	56	63	65	66	67	68	69	72	73	78
Quantity of radiolarians per 1 gr. of rock	>1000	50–100	200–500	20–40	10–15	200–500	20–40	1–5	200–500	1–5	>1000	20–40	>1000	>1000	>1000
Paleotemperature coefficient	1.17	1.14	3.25	0.57	0.67	0.88	0.67	0.67	1	0.5	1.19	1.57	3	2.06	2.08
Species diversity Sphaerellaria /Aculearia: D_3fr_2: 77/32	21/18	14/14	26/8	4/7	2/3	7/8	2/3	2/3	5/5	1/2	19/16	11/7	42/14	33/16	27/13
	Rdm-1: 42/23			Rdm-2: 12/10							Rdm-3: 73/30				
Borisella mediforma (Won)															
Helioentactinia gudymovae Afanasieva															
Astroentactinia tantilla Nazarov															
Polyentactinia zhamoidai Afanasieva															
Moskovistella rozanovi Afanasieva															
Radiobisphaera menneri Afanasieva															
Polyentactinia kossistekensis Nazarov															
Astroentactinia vishnevskayae Afanasieva															
Astroentactinia tikhomirovi Afanasieva															
Borisella bykovae Afanasieva															
Moskovistella khaini Afanasieva															
Bientactinosphaera variacanthina (Foreman)															
Ornatoentactinia solita Afanasieva															
Bientactinosphaera morozovi Afanasieva															
Somphoentactinia gavrilovi Afanasieva															
Spongentactinella veles (Foreman)															
Astroentactinia crassata Nazarov															
Bientactinosphaera grandis (Nazarov)															
Spongentactinella olafi Afanasieva															
Astroentactinia paronae (Hinde)															
Haplentactinia alekseevi Afanasieva															
Russirad kazintsovae Afanasieva															
Ornatoentactinia agarkovi Afanasieva															
Entactinia patorovaria Afanasieva															
Bientactinosphaera australis (Aitchison)															
Moskovistella victorialis Afanasieva															
Borisella maksimovae Afanasieva															

Table 3. (Contd.)

Interval, m	120.9–124.0	106.0–107.0	105.0–106.0	104.1–104.6	98.0–99.0	81.6–83.0	75.0–77.3		73.5–74.0	73.3–73.5		73.0–73.3	71.9–72.4	71.4–71.9	68.9–69.3
Sample number	8	28	29	34	40	56	63	65	66	67	68	69	72	73	78
Quantity of radiolarians per 1 gr. of rock	>1000	50–100	200–500	20–40	10–15	200–500	20–40	1–5	200–500	1–5	>1000	20–40	>1000	>1000	>1000
Paleotemperature coefficient	1.17	1.14	3.25	0.57	0.67	0.88	0.67	0.67	1	0.5	1.19	1.57	3	2.06	2.08
Species diversity Sphaerellaria /Aculearia: D_3fr_2: 77/32	21/18	14/14	26/8	4/7	2/3	7/8	2/3	2/3	5/5	1/2	19/16	11/7	42/14	33/16	27/13
	Rdm-1: 42/23			Rdm-2: 12/10							Rdm-3: 73/30				
Tetragregnon quadrispinosa (Foreman)															
Retisphaera exquisita (Aitchison)															
Bientactinosphaera maslakovae Afanasieva															
Bientactinosphaera conglobata (Nazarov)															
Haplentactinia bornazi Afanasieva															
Ornatoentactinia spartaci Afanasieva															
Radiobisphaera assidera (Nazarov)															
Ornatoentactinia beljaevorum Afanasieva															
Ornatoentactinia spinisica Afanasieva															
Moskovistella allbororum Afanasieva															
Astroentactinia biaciculata Nazarov															
Bientactinosphaera pinica Afanasieva															
Bientactinosphaera hystricosa (Foreman)															
Haplentactinia barskovi Afanasieva															
Entactinia bogdanovi Afanasieva															
Moskovistella octoradiata Afanasieva															
Entactinia bifida Afanasieva															
Spongentactinella corynacantha Naz. et Orm.															
Moskovistella sincera Afanasieva															
Bientactinosphaera symphypora (Foreman)															
Moskovistella mira Afanasieva															
Helioentactinia polyacanthina (Foreman)															
Helioentactinia perjucunda Nazarov et Ormiston															
Haplentactinia aperticuva (Aitchison)															

Table 3. (Contd.)

Interval, m	120.9–124.0	106.0–107.0	105.0–106.0	104.1–104.6	98.0–99.0	81.6–83.0	75.0–77.3		73.5–74.0	73.3–73.5		73.0–73.3	71.9–72.4	71.4–71.9	68.9–69.3
Sample number	8	28	29	34	40	56	63	65	66	67	68	69	72	73	78
Quantity of radiolarians per 1 gr. of rock	>1000	50–100	200–500	20–40	10–15	200–500	20–40	1–5	200–500	1–5	>1000	20–40	>1000	>1000	>1000
Paleotemperature coefficient	1.17	1.14	3.25	0.57	0.67	0.88	0.67	0.67	1	0.5	1.19	1.57	3	2.06	2.08
Species diversity Sphaerellaria /Aculearia: D_3fr_2: 77/32	21/18	14/14	26/8	4/7	2/3	7/8	2/3	2/3	5/5	1/2	19/16	11/7	42/14	33/16	27/13
	Rdm-1: 42/23			Rdm-2: 12/10							Rdm-3: 73/30				
Borisella pantosompha (Foreman)															
Entactinia herculea Foreman															
Borisella mariae Afanasieva															
Ornatoentactinia klevtsovae Afanasieva															
Astroentactinia rusaevi Afanasieva															
Bientactinosphaera miletenkoi Afanasieva															
Polyentactinia craticulata Foreman															
Entactinia micula Foreman															
Bientactinosphaera cancellicula (Foreman)															
Apophysisphaera profundisculus (Aitchison)															
Helioentactinia aster Aitchison															
Moskovistella baccata Afanasieva															
Cancellosphaere varia (Won)															
Borisella primitiva Afanasieva															
Spongentactinella windjanensis Nazarov															
Bientactinosphaera inusitata (Foreman)															
Helioentactinia unimana (Nazarov)															
Meschedea crassicortex Won															
Moskovistella lucet Afanasieva															
Retentactinia kelleri Afanasieva															
Entactinia paula Foreman															
Entactinia diversita Nazarov															
Moskovistella additiva (Foreman)															
Retentactinia longa Won															
Bientactinosphaera egindyensis (Nazarov)															
Bientactinosphaera guangxiensis (Li et Wang)															
Radiobisphaera domanicensis (Bykova)															

Table 4. Distribution of Aculearia species in the section of Borehole Shuda-Yag-1003

Interval, m	120.9–124.0	106.0–107.0	105.0–106.0	104.1–104.6	98.0–99.0	81.6–83.0	75.0–77.3		73.5–74.0	73.3–73.5		73.0–73.3	71.9–72.4	71.4–71.9	68.9–69.3
Sample number	8	28	29	34	40	56	63	65	66	67	68	69	72	73	78
Quantity of radiolarians per 1 gr. of rock	>1000	50–100	200–500	20–40	10–15	200–500	20–40	1–5	200–500	1–5	>1000	20–40	>1000	>1000	>1000
Paleotemperature coefficien	1.17	1.14	3.25	0.57	0.67	0.88	0.67	0.67	1	0.5	1.19	1.57	3	2.06	2.08
Species diversity Sphaerellaria /Aculearia: D_3fr_2: 77/32	21/18	14/14	26/8	4/7	2/3	7/8	2/3	2/3	5/5	1/2	19/16	11/7	42/14	33/16	27/13
	Rdm-1: 42/23			Rdm-2: 12/10							Rdm-3: 73/30				
Ceratoikiscum spinosiarcuatum Foreman															
Ceratoikiscum? cf. *vimenum* Nazarov, Ormiston															
Palaeoscenidium phalangium Aitchison															
Nazarovites mikhailovae Afanasieva															
Ceratoikiscum goodbodyi Cheng															
Ceratoikiscum avimexpectans Deflandre															
Ceratoikiscum planistellare Foreman															
Ceratoikiscum delicatum Cheng															
Ceratoikiscum stellatum Aitchison															
Palaeoscenidium delicatum Aitchison															
Palaeoscenidium tabernaculum Aitchison															
Ceratoikiscum spinosum Cheng															
Nazarovites pinnula Afanasieva															
Ceratoikiscum ukhtensis Afanasieva															
Nazarovites bioculus Afanasieva															
Palacantholithus stellatus Deflandre															
Palaeoscenidium cladophorum Deflandre															
Palaeoscenidium robustum Aitchison															
Palaeoscenidium scaurum Afanasieva															
Ceratoikiscum robustum Aitchison															
Circulaforma delicata Cheng															
Palacantholithus curvativus Afanasieva															
Nazarovites aprelevkensis Afanasieva															
Ceratoikiscum incomptum Nazarov															
Ceratoikiscum simplum Cheng															
Palaeothalomnus arrhinia (Foreman)															
Ceratoikiscum bujugum Foreman															
Bissylentactinia? cf. *rudicula* Nazarov															
Ceratoikiscum araneosum Afanasieva															
Palaeothalomnus timokhini Afanasieva															
Palaeothalomnus quadriramosum (Foreman)															
Palhindeolithus ambiguus Deflandre															

tion (Nazarov and Ormiston, 1983) and shows its last appearance in this subassemblage.

Most representative species, which determine the general aspect of radiolarian fauna in question (Table 2), are *Astroentactinia tantilla* Nazarov, *Ceratoikiscum avimexpectans* Deflandre, *Helioentactinia gudymovae* Afanasieva, *Nazarovites mikhailovae* Afanasieva, and *Palaeoscenidium scaurum* Afanasieva (Plate I; figs. 2, 4, 12, 14, 17). In addition to them, rather widespread are *Astroentactinia tikhomirovi* Afanasieva, *Entactinia bogdanovi* Afanasieva, *Radiobisphaera menneri* Afanasieva, *Tetragregnon quadrispinosa* (Foreman), *Palaeoscenidium tabernaculum* Aitchison, and *Ceratoikiscum spinosiarcuatum* Foreman (Plate I; figs. 3, 5, 7, 11, 13, 16).

First representatives of *Bientactinosphaera conglobata* (Nazarov) and *Polyentactinia kossistekensis* Nazarov (Plate I; figs. 6, 10) appearing in the early Domanik time reach their flourishing phase in the late Frasnian.

The Rdm-2 subassemblage is confined to cherty limestone of the middle member of the Domanik Formation and to lower beds of its upper member (Fig. 2; Table 1). Its range corresponds to an upper part of the ammonite *Nordiceras timanicum* Zone and to an upper part of the conodont *Palmatolepis hassi* Zone (Becker *et al.*, 1995; House *et al.*, in press) (Table 2).

It is likely that conditions in the paleobasin of the Domanik time were unfavorable for the organic world evolution. The Rdm-2 subassemblage marks a noticeable decrease in abundance of radiolarians (from 20–40 to single specimens per 1 g of sediment) and extremely low diversity of spherical Sphaerellaria (12 species) and echinate Aculearia forms (10 species). The proportion between spherical and echinate species is inversed here, because Aculearia forms are more abundant (Fig. 2, Tables 3, 4).

Representative radiolarian species of the Rdm-2 subassemblage are *Entactinia bifida* Afanasieva and *Moskovistella mira* Afanasieva (Table 2; Plate II, figs. 1, 2), as they were encountered in this subassemblage only, though as individual specimens. These species have contiguous and doubled spines that indicate most likely an abnormality and, hence, the unfavorable ecology during the middle Domanik time.

It is impossible to distinguish the type echinate species of the subassemblage, because *Aculearia* representatives prevail over others at every particular level of the section. We can point out only several species, which are more often found in the middle Domanik deposits. These are *Palacantholithus stellatus* Deflandre, *Circulaforma delicata* Cheng, *Ceratoikiscum stellatum* Aitchison, and *C. planistellare* Foreman (Plate II, figs. 7–10).

Remarkable among radiolarians of the Rdm-2 subassemblage are *Spongentactinella corynacantha* Nazarov et Ormiston (Plate II, fig. 5) that was found for the first time in the lower Frasnian deposits (Nazarov and Ormiston, 1983) and first appearing species *Moskovistella octoradiata* Afanasieva, *M. sincera* Afanasieva and *Bientactinosphaera symphypora* (Foreman) (Plate II, figs. 3, 4, 6).

The Rdm-3 subassemblage characterizes the fourth, most calcareous unit of the upper member of the Domanik Formation (Fig. 2; Table 1). Its range corresponds to the conodont *Palmatolepis jamieae* Zone coupled with the lower part of the *Palmatolepis rhenana* Zone (House *et al.*, in press) (Table 2).

It is likely that a general climatic warming at the end of the Domanik time resulted in stabilization of warm conditions in the sea basin. These changes in habitat conditions gave rise to a sharp increase of radiolarian abundance (more than 1000 specimens per 1 g of rock). The subassemblage shows a very high content of spherical Sphaerellaria (up to 93%) represented by 73 species (compare to 42 Sphaerellaria species in the lower member and to 12 species only in the middle one, Fig. 2, Table 3). Echinate Aculearia species from the upper part of the section are represented by 30 species, and their diversity is thus nearly similar to that in the lower member (23 species), but three times higher than in the Rdm-2 subassemblage from the middle member (10 species, Fig. 2, Table 4).

Representative species of the Rdm-3 subassemblage, which appear for the first time at the end of the Domanik time, are (Table 2) *Astroentactinia rusaevi* Afanasieva, *Borisella mariae* Afanasieva, *Bientactinosphaera guangxiensis* (Li et Wang), *Entactinia micula* Foreman (Plate III, figs. 1, 9, 12, 15), as well as *Palaeothalomnus timokhini* Afanasieva, *P. arrhinia* (Foreman) (Plate III, figs. 30, 32). Most abundant at this level are *Moskovistella allbororum* Afanasieva, *M. khaini* Afanasieva, *M. rozanovi* Afanasieva, *M. victorialis* Afanasieva, *Borisella bykovae* Afanasieva, *B. maksimovae* Afanasieva, *Bientactinosphaera miletenkoi* Afanasieva, *Ornatoentactinia solita* Afanasieva (Plate III, figs. 3–8, 10, 14), *Spongentactinella olafi* Afanasieva, *Polyentactinia zhamoidai* Afanasieva, *Haplentactinia alekseevi* Afanasieva, *H. barskovi* Afanasieva, *Nazarovites bioculus* Afanasieva, *N. pinnula* Afanasieva, *Ceratoikiscum ukhtensis* Afanasieva, *C. araneosum* Afanasieva, *Palaeotripus gogoense* Aitchison (Plate III, figs. 17, 19–24, 27, 29), and *Ceratoikiscum stellatum* Aitchison (Plate II, fig. 9).

Characteristic of the upper part of the Domanik Formation are radiolarians appearing for the first time in Middle Devonian and then flourishing and dying out at the end of the Domanik time. Among those are *Radiobisphaera assidera* (Nazarov), *Ornatoentactinia spartaci* Afanasieva (Plate III, figs. 11, 13), and *Spongentactinella windjanensis* Nazarov (Plate III, fig. 18).

Radiolarian species *Astroentactinia paronae* (Hinde), *Entactinia paula* Foreman (Plate III, figs. 2, 16), *Ceratoikiscum incomptum* Nazarov, *C. goodbodyi* Cheng, *C. simplum* Cheng, *Palaeothalomnus quadriramosum* (Foreman) (Plate III, figs. 25, 26, 28, 31), which

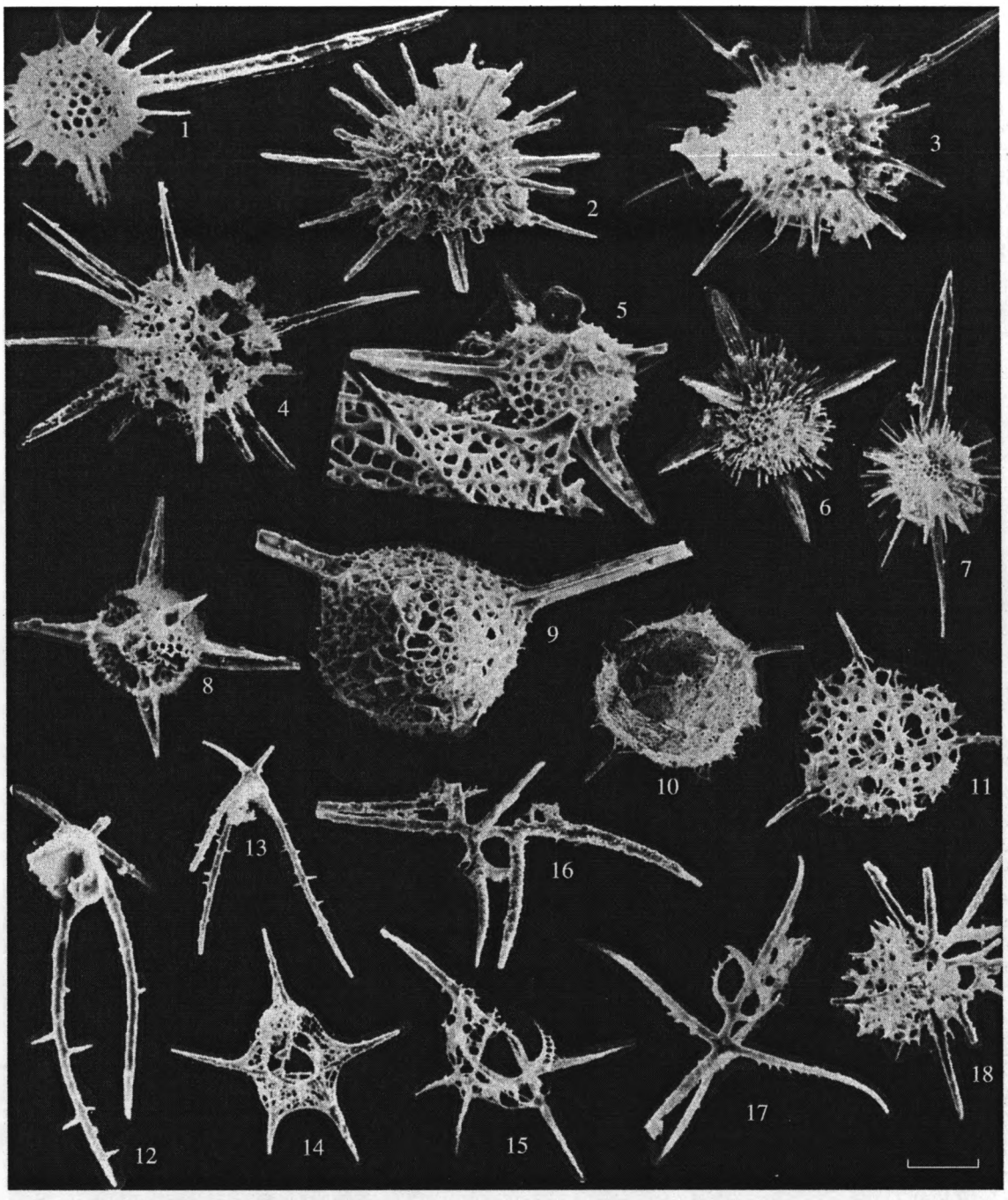


Plate I. Radiolarian subassemblage Rdm-1, Upper Devonian, middle Frasnian, Domanik Formation, southern part of the Timan–Pechora basin.

Section of Borehole Shuda-Yag-1003: figs. 1, 3, 7, 8, 10, 13, 14, 16, 17 from Sample 8 (interval 120.9–124.0 m); figs. 2, 4, 11, 12, 15 from Sample 28 (int. 106–107 m); figs. 5, 6, 9, 18 from Sample 29 (int. 105–106 m).

(1) *Astroentactinia vishnevskayae* Afanasieva, FF-P001/034-04134 (marker=67 μm); (2) *A. tantilla* Nazarov, FF-P001/042-11901 (=63 μm); (3) *A. tikhomirovi* Afanasieva, FF-P001/048-04108 (=56 μm); (4) *Helioentactinia gudymovae* Afanasieva, FF-P001/058-10507 (=50 μm); (5) *Entactinia bogdanovi* Afanasieva, FF-P001/115-04419 (=33 μm); (6) *Bientactinosphaera conglobata* (Nazarov), FF-P001/025-04404 (=125 μm); (7) *Radiobisphaera menneri* Afanasieva, FF-P001/014-04010 (=100 μm); (8) *Bientactinosphaera morozovi* Afanasieva, FF-P001/116-04122 (=50 μm); (9) *Russirad kazintsovae* Afanasieva, FF-P001/026-04524 (=77 μm); (10) *Polyentactinia kossistekensis* Nazarov, FF-P001/010-04003 (=100 μm); (11) *Tetragregnon quadrispinosa* (Foreman), FF-P001/001-04202 (=50 μm); (12) *Palaeoscenidium scaurum* Afanasieva, FF-P001/099-04304 (=50 μm); (13) *P. tabernaculum* Aitchison, FF-P001/080-04027 (=100 μm); (14) *Ceratoikiscum avimexpectans* Deflandre, FF-P001/075-04021 (=100 μm); (15) *C.* ? *vimenum* Nazarov et Ormiston, FF-P001/082-04303 (=50 μm); (16) *C. spinosiarcuatum* Foreman, FF-P001/112-04031 (=50 μm); (17) *Nazarovites mikhailovae* Afanasieva, FF-P001/095-10306 (=50 μm); (18) *N. aprelevkensis* Afanasieva, FF-P001/097-04411 (=67 μm).

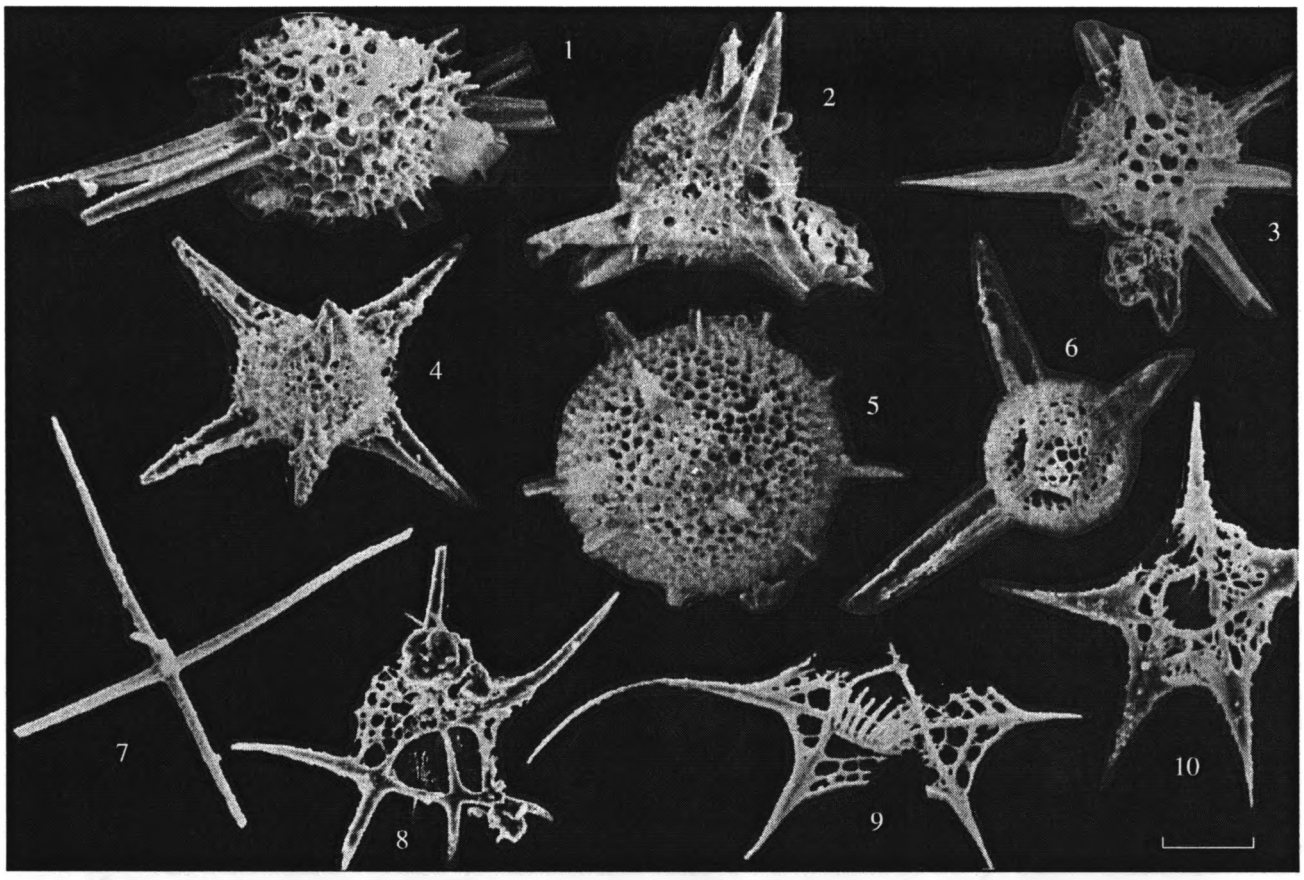


Plate II. Radiolarian subassemblage Rdm-2, Upper Devonian, middle Frasnian, Domanik Formation, southern part of the Timan–Pechora basin.

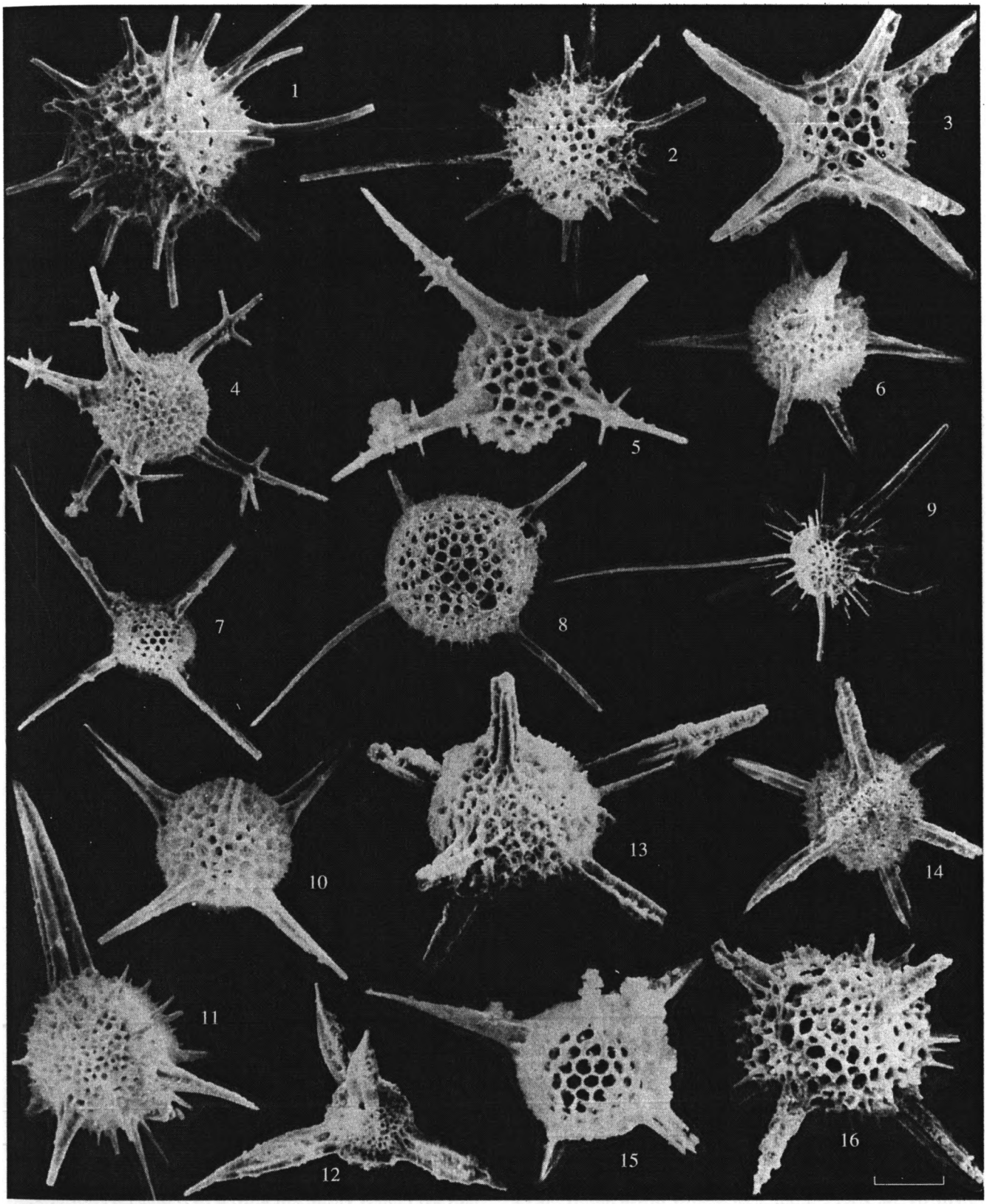
Section of Borehole Shuda-Uan-1003: figs. 1, 3, 7–10 from Sample 34 (int. 104.1–104.6 m); fig. 2 from Sample 65 (int. 75.0–77.3 m); figs. 4–6 from Sample 56 (int. 81.6–83.0 m).

(1) *Entactinia bifida* Afanasieva, FF-P001/029-04604 (marker=67 μm); (2) *Moskovistella mira* Afanasieva, FF-P001/030-04633 (=33 μm); (3) *M. octoradiata* Afanasieva, FF-P001/114-04601 (=50 μm); (4) *M. sincera* Afanasieva, FF-P001/109-04609 (=50 μm); (5) *Spongentactinella corynacantha* Nazarov et Ormiston, FF-P001/061-04621 (=42 μm); (6) *Bientactinosphaera symphypora* (Foreman), FF-P001/135-04608 (=50 μm); (7) *Palacantholithus stellatus* Deflandre, FF-P001/089-04529 (=100 μm); (8) *Circulaforma delicata* Cheng, FF-P001/066-04602 (=67 μm); (9) *Ceratoikiscum stellatum* Aitchison, FF-P001/076-04536 (=67 μm); (10) *C. planistellare* Foreman, FF-P001/074-04533 (=50 μm).

Plate III. Radiolarian subassemblage Rdm-3: Upper Devonian, middle Frasnian, Domanik Formation, southern part of the Timan–Pechora basin.

Section of Borehole Shuda-Yag-1003: figs. 1, 3, 9, 19, 28, 29 from Sample 68 (int. 73.0–73.3 m); figs. 2, 6, 17, 18, 20, 26 from Sample 72 (int. 71.9–72.4 m); figs. 7, 12 from Sample 78 (int. 68.9–69.3 m); figs. 10, 11, 14, 25, 27, 30, 31 from Sample 73 (int. 71.4–71.9 m); fig. 15 from Sample 69 (int. 73.0–73.3 m). Exp. 1904 at the Lyajol River: figs. 4, 5, 8, 13, 16, 21–24, 32 from Sample 6.

(1) *Astroentactinia rusaevi* Afanasieva, FF-P001/107-04726 (marker=50 μm); (2) *Astroentactinia paronae* (Hinde), FF-P001/047-08627 (=67 μm); (3) *Moskovistella khaini* Afanasieva, FF-P001/041-04727 (=37 μm); (4) *Moskovistella allbororum* Afanasieva, FF-P001/033-09512 (=56 μm); (5) *Moskovistella victorialis* Afanasieva, FF-P001/032-09628 (=50 μm); (6) *Moskovistella rozanovi* Afanasieva, FF-P001/117-05132 (=50 μm); (7) *Borisella maksimovae* Afanasieva, FF-P001/036-04919 (=83 μm); (8) *Borisella bykovae* Afanasieva, FF-P001/037-09537 (=50 μm); (9) *Borisella mariae* Afanasieva, FF-P001/051-04708 (=133 μm); (10) *Bientactinosphaera miletenkoi* Afanasieva, FF-P001/022-08831 (=50 μm); (11) *Bientactinosphaera assidera* (Nazarov), FF-P001/101-08821 (=56 μm); (12) *Bientactinosphaera guangxiensis* (Li et Wang), FF-P001/104-04928 (=90 μm); (13) *Ornatoentactinia spartaci* Afanasieva, FF-P001/052-09705 (=45 μm); (14) *Ornatoentactinia solita* Afanasieva, FF-P001/043-08804 (=67 μm); (15) *Entactinia micula* Foreman, FF-P001/028-04834 (=33 μm); (16) *Entactinia paula* Foreman, FF-P001/019-09627 (=67 μm); (17) *Spongentactinella olafi* Afanasieva, FF-P001/056-08514 (=100 μm); (18) *S. windjanensis* Nazarov, FF-P001/057-08515 (100 μm); (19) *Polyentactinia zhamoidai* Afanasieva, FF-P001/011-04722 (50 μm); (20) *Haplentactinia barskovi* Afanasieva, FF-P001/005-09609 (=33 μm); (21) *H. alekseevi* Afanasieva, FF-P001/038-09621 (=67 μm); (22) *Nazarovites bioculus* Afanasieva, FF-P001/092-09834 (=56 μm); (23) *N. pinnula* Afanasieva, FF-P001/093-09508 (=50 μm); (24) *Ceratoikiscum ukhtensis* Afanasieva, FF-P001/106-09835 (=67 μm); (25) *C. incomptum* Nazarov, FF-P001/072-08811 (=83 μm); (26) *C. goodbodyi* Cheng, FF-P001/077-08520 (=67 μm); (27) *C. araneosum* Afanasieva, FF-P001/073-08706 (=63 μm); (28) *C. simplum* Cheng, FF-P001/068-04810 (=67 μm); (29) *Palaeoscenidium tabernaculum* Aitchison, FF-P001/080-04807 (=100 μm); (30) *Palaeothalomnus timokhini* Afanasieva, FF-P001/086-08713 (=56 μm); (31) *P. quadriramosum* (Foreman), FF-P001/105-08721 (=56 μm); (32) *P. arrhinia* (Foreman), FF-P001/085-09504 (=110 μm).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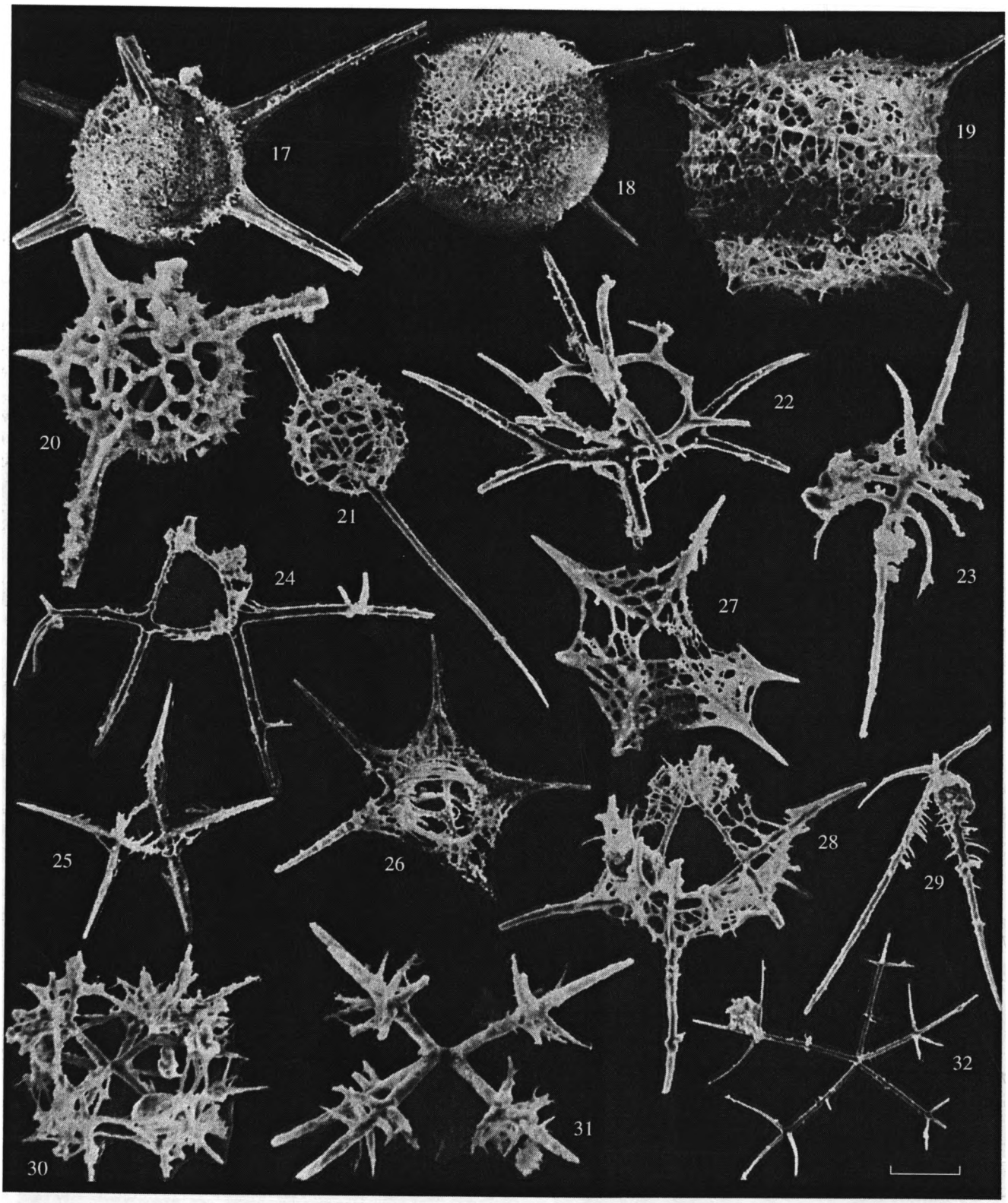

Plate III. (Contd.)

appeared first in the late Domanik time, became widespread and reached their flourishing phase in the late Frasnian–Famennian.

SEDIMENTATION CONDITIONS IN THE DOMANIK BASIN

Frasnian deposits of the Timan–Pechora basin characterize one major transgression–regression sedimentation cycle (Kushnareva, 1972; Tikhii, 1975; Yudina and Moskalenko, 1994; Tikhomirov, 1995). In the early Frasnian, a plain with fluvial, lacustrine and lagoonal deposits was located in the Russian platform. The subsequent transgression advanced from the Uralian paleobasin gradually covering the vast territory to form marginal, epicontinental seas similar to the Timan–Pechora paleobasin. In the middle Frasnian, the sea transgression advanced three times into the Russian platform. These events were followed by the general sea regression at the end of the late Frasnian.

The maximum transgression and its stabilization are distinctive features of the Domanik time. The unique character of Domanik deposits is however related to the peculiar regional phase of tectonic activity. On the one hand, the Frasnian Age corresponds the cis-Timan aulacogen formation associated with eruptions of basaltic lavas and deposition of strata rich in volcanic ash. On the other hand, it was a period of intense submarine volcanic activity in the Uralian paleobasin (Klevtsova *et al.*, 1998; Maksimova, 1970, 1975; Tikhii, 1975; Tikhomirov, 1967, 1995; Klevtsova and Afanasieva, 1998) (Fig. 1). The volcanic activity associated with development of the cis-Timan aulacogen and deep faults was probably the main factor that created peculiar ecological environments in the Domanik basin, i.e., a pulsating enrichment of the basin with silica and "outbursts" of the biological productivity.

Layering of the Domanik deposits is extremely fine, reflecting the pulsating evolution of the basin at all levels, from the whole sequence and its members to bed packets, individual layers, and even fine lamina visible in thin sections only (Afanasieva and Mikhailova, 1996, 2000). Larger evolutionary cycles were probably controlled by activation and cessation of submarine volcanism and by silica inflow from hydrothermal systems of deep-seated magmatic chambers (Klevtsova *et al.*, 1998; Maksimova, 1970, 1975). In general, the Domanik Formation sequence shows two levels of abrupt changes in species composition and abundance of radiolarians, acritarchs, tasmanites, tentaculites, and other organic remains, as well as two maximums of pyritization and silicification of deposits. Smaller biotic fluctuations recorded in sediments likely reflect oscillations of climatic and ecological factors, which undoubtedly caused ecosystem rearrangements (Afanasieva and Mikhailova, 1994, 1995, 1996, 1998, 2000; Afanasieva, 1998).

One of the distinctive features of Domanik deposits is a high total content of silica in the rocks. A high content of dissolved silica was probably a consequence of intense submarine volcanic activity. The average SiO_2 content in the rocks (except for pure cherts) is 37.2%. The initial high SiO_2 content in waters of the Domanik basin is evident not only from fauna distribution, but from a very early silica precipitation as well. Silica, as a rule, does not immediately precipitate from supersaturated sea water but forms a colloid first and accumulates on the bottom in abundance in the form of gel globules (Maksimova, 1970). Some admixtures, especially the organic substance retard the silica crystallization. The higher the content of organic substance in sediments, the worse is crystallinity of siliceous mass in the latter (Khvorova and Dmitrik, 1972). Siliceous skeleton remains merely plunge into the gel to be gradually dissolved. "Shadows" of skeletons of various organisms can be often observed in bituminous shales, where they are dissolved in and merged with surrounding cherts. In addition, deposits of the Domanik Formation enclose abundant calcareous structures of diagenetic origin, which are lenticular, more or less elongated in shape. These calcareous or siliceous–calcareous concretions occurring sometimes in absolutely barren cherts are very rich in organic remains, first of all in radiolarians, sponge spicules, and acritarchs. The remains are likely preserved owing to partial calcitization of concretion matrix enclosing them. Exactly this diagenetic calcitization probably protected skeletons of numerous organisms, which populated the Domanik basin, from their dissolution in mud (Tikhomirov, 1995).

One more characteristic feature of the Domanik Formation deposits is monogenetic accumulations of Linguloidea, Buchiola, Tentaculita, Radiolaria, and Sphaerellaria (most likely of the Algae–Acritarcha type). As a rule, they are associated with mass accumulations of single-celled green algae tasmanites (Tel'nova, 1995). The accumulations may occur as interlayers of organogenic or cherty limestones, or as organogenic "placers" of skeletons or imprints on bedding planes of clayey and siliceous shales or siliciliths barren of fauna. It is likely that skeletons have not been preserved in the latter (?), or organisms died "suddenly" just at the moment of sediment accumulation. Tentaculita remains are especially abundant in the Domanik Formation and occur throughout its section in all rock varieties, being concentrated on bedding planes (Kushnareva, 1963). Forming sometimes uniform "felt" sheets or placers on bedding planes of combustible shales, Tentaculita remains do not occur within the rock mass itself. In contrast, chaotic accumulations of Tentaculita skeletons are often observed inside limestone beds, where their content can be as high as 85–95%. Tentaculitid limestones themselves are of insignificant thickness (less than 5–6 cm and usually several mm). These chaotic accumulations of Tentaculita with a small admixture of mud indicate a sudden extinction and subsequent burial of their skeletons on the bottom.

Accommodating themselves to habitat conditions, living organisms are capable to change their own morphology. This means that studying the structure of organic remains (skeletons), we can infer what mode of life the organisms led. It is most likely that the skeleton shape, as well as proportions between the skeleton and cytoplasm masses of a cell, determine the optimal dwelling conditions and submergence depth of radiolarians in the water mass. On the other hand, the deep-water habitats enriched in dissolved silica lead to formation of a heavy massive skeleton of an organism, whereas dwellers of surface waters have cellular skeletons. In any case, any organism with a larger specific mass of its body will inhabit deeper waters without unreasonable energy consumption for rising up into higher water layers. Hence, morphological features of radiolarian tests and character of their biocoenoses are closely related to their habitat environments and change by passing from deep-water to shallow-water sedimentation settings. These features also depend on water temperature regime in a paleobasin.

In present-day oceans, radiolarians live at all depth levels, from the surface water layer to the depth of 5000 m. They are most abundant within the depth interval of 10–300 m. The maximum content of radiolarians, except for skeleton fragments, is as high as 30% of the sediment mass. This is well compatible with the plankton structure, though skeletons of one and the same species are preserved differently in different-type sediments (Petrushevskaya, 1981, 1986). Analyzing changes in abundance rates of higher taxons of recent radiolarians, Kruglikova (1993, 1995) established that prevalence of bilateral–symmetrical Nassellaria forms over spherical Sphaerellaria species indicates colder habitat environments of a given radiolarian assemblage, and vice versa.

Nassellaria forms are unknown from Paleozoic deposits. They are likely to originate from Paleozoic radiolarians of the *Popofskyellum* genera, which had conical segmented test with pylome and subspherical apical segment. On the other hand, another group of Paleozoic radiolarians, namely, the echinate Aculearia forms inhabited the same ecological niche of deep and bottom waters along with Pylomaria. Taking this into account, we may calculate the paleotemperature coefficient Rt = Sphaerellaria/Aculearia for Paleozoic radiolarians.

According to the coefficient values (Rt ≤ 1), the prevalence of echinate Aculearia species over spherical Sphaerellaria forms in the Domanik Formation indicates a relatively cold state of bottom waters in the Timan–Pechora paleobasin (Afanasieva and Mikhailova, 1995). For the early Domanik time, this paleoclimatic coefficient varied from 1.14 to 3.25. In the middle Domanik time, the coefficient was minimal, not exceeding 0.57–0.88. In the late Domanik time, it increased again, approaching the peak value of 3.00 (Fig. 2, Tables 3, 4).

Hence, the Domanik Formation yields two morphological groups of radiolarians: spherical Sphaerellaria and echinate Aculearia forms confined to different sea zones and sediment types. According to quantitative proportions and taxonomic composition, the distinguished radiolarian assemblages characterize the relatively warm or cold habitats at different depth levels of the Domanik paleobasin. It is of interest that the near-bottom echinate Aculearia forms are almost equally abundant throughout the Domanik section. In contrast, abundance of spherical Sphaerellaria species is quite variable: they are rare in the lower member, subordinate in the middle, and most abundant and diverse in the upper member. Apparently, the ecological situation of the middle Domanik time was favorable for evolution of relatively cryophilic echinate forms only. These Aculearia forms led a near-bottom mode of life and became dominant among radiolarians under such conditions.

It is possible that only neritic radiolarian species existed in a remote geological past and inhabited not the oceans, but mainly bottom waters of relatively shallow epicontinental and marginal seas (Petrushevskaya, 1981, 1986; Afanasieva and Vishnevskaya, 1993a, 1993b; Afanasieva and Mikhailova, 1994, 1995). Oceanic species have not yet existed during the Paleozoic (Afanasieva and Vishnevskaya, 1993a, 1993b). There is a common opinion, however, that all radiolarians are planktonic organisms, and that radiolarian oozes represent only deep-water deposits. This seems to be true for all Cenozoic and many Mesozoic deposits (Afanasieva and Vishnevskaya, 1993a, 1993b). Nonetheless, Khabakov (1932, p. 223) who studied Paleozoic radiolarians, pointed out long ago that "contrary to a common prejudice, abundant radiolarian remains in an ancient sediment do not evidence for the abyssal origin of host sediments. Radiolarites of continental shields belong mostly to bathyal, neritic, and even lagoonal deposits". Later on, in 1951, Kaptarenko-Chernousova (1951, p. 159) reported "actual data on a small dwelling depth of radiolarians" from the Paleogene clays overlying marls of the Kiev Horizon. Bykova (1955, p. 111) who studied the Domanik radiolarians in the Volga–Urals province concluded that "they could occur in littoral sediments". In this connection, the Early Carboniferous benthic radiolarians of the *Caspiaza* genus having pylome and detected in organogenic-detrital deposits of the Karachaganak Massif, northern Caspian Sea region, are of special interest. The highest concentration of near-bottom *Caspiaza* forms is confined to deposits of an upper shelf, not far away from shallow-water algal biostromes (Afanasieva, 1987). These facts are assiduously ignored by many researchers, and the problem of a shallow-water origin of ancient radiolarians is diligently hushed up.

If Paleozoic echinate and pylome radiolarians inhabited water layers neat the bottom, they were likely tolerant to a high silica concentration and associated hydrogen sulfide contamination. On the other hand, the

fast burial of skeletons, saturation of sediments with, low temperature and low pH in bottom waters were favorable for accumulation and preservation of abyssal and planktonic radiolarian forms in siliceous sediments and cherty limestones. Their fast burial in the Domanik sediments supersaturated with silica is also evident from the widespread acritarch cells crustified with silica and preserving their lifetime form and details of the organic wall sculpture (Afanasieva and Mikhailova, 1998).Thus, morphological peculiarities of fossils, their diversity, and cyclic changes of taphocoenoses reflect various habitat environments and significant ecological rearrangements during the Domanik time.

According to one hypothesis (Nalivkin, 1955, 1956), the Timan–Pechora paleobasin was located in a warm tropical belt, and the paleomagnetic equator of the Frasnian time crossed the eastern part of the Russian platform along the 50° meridian (Tikhii, 1975) (Fig. 1). This inference is based on the presence of barrier reefs in the Uralian paleobasin. The development of coral reefs indicates a strong surf, pure water, tropical climate, and the average temperature of about 20°C. Reefs, bioherms, and banks also formed since the Frasnian in the Timan–Pechora basin along the edge of a shallow-water shelf and within an uncompensated depression among shoals (Menner *et al.*, 1995). Platy, crustal, and massive forms of stromatoporoids and blue-green algae were dominant reef-building organisms of the Domanik time. Fantastic diversity of planktonic Sphaerellaria forms and their prevalence over abyssal echinate Aculearia species in the lower and, especially, in the upper members of the Domanik Formation can be regarded as arguments in favor of the tropical climate at that time. Rhizocretions in sediments indicate a small depth of the paleobasin. Mass accumulations of tasmanites testify the same. "Outbursts" of bioproductivity of unicellular blue-green algae are recorded in deposits of various ages and regions, where they accumulated under conditions of maximal sea transgressions and inflow of waters enriched in biogenic substance derived from flooded coastal plains (Efremova, 1987).

The presence of sponge spicules in sediments is a very interesting fact greatly important for the assessment of the paleoecological conditions in the Domanik sea. Some times ago, sponge spicules from Domanik deposits were either mentioned only (Kushnareva, 1959, 1963; Vishnevskaya *et al.*, 1993), or even the occurrence of sponges in the Timan–Pechora paleobasin was merely denied (Maksimova, 1970). Investigation of microfossils and Domanik rocks under the electron microscope allowed us to establish for the first time the presence of silicic tetraradiate sponge spicules illustrating a specific mode of skeleton growth and having central canals (Afanasieva and Mikhailova, 1994, 1995a, 1995b, 1998). Such morphological features of spicules (Koltun, 1961) may indicate that sponges of the Domanik time dwelled at the depth of 200 m.

Data presented above suggest that sedimentation in the Timan–Pechora sea and evolution of ecosystems during the Domanik time took place at the terminal transgression stage in the outer shelf zone of a shallow marginal sea, where the depth range was 100–200 m even in the most deep Ukhta segment of the basin. This conclusion confirms the hypothesis of shallow-water conditions in the Paleozoic seas (Strakhov, 1937, 1939; Maksimova, 1970; Timofeev and Kholodov, 1984).

CONCLUSION

(1) A rich radiolarian assemblage of 127 species was macerated for the first time from the Domanik deposits, where these fossils associate with sponge spicules, silicified acritarchs cells, and rhizocretions.

(2) Three subassemblages Rdm-1 (lower), Rdm-2 (middle), and Rdm-3 (upper) with different abundance rates and taxonomic compositions of radiolarians are distinguished as principal components of the *Moskovistella allbororum–Ceratoikiscum ukhtensis* radiolarian assemblage.

(3) Two morphological groups of radiolarians distinguished in the Domanik Formation, namely, planktonic spherical Sphaerellaria and near-bottom echinate of *Aculearia* forms show selective confinement to different sea zones and types of sediments.

(4) Abundance and species diversity of near-bottom Aculearia species are were almost constant during the Domanik time, whereas planktonic Sphaerellaria species keenly responded to changes in the habitat conditions.

(5) According to calculated paleotemperature coefficients, which illustrate prevalence of echinate Aculearia species over spherical Sphaerellaria forms in the studied sediments, near-bottom waters in the Domanik paleobasin were relatively cold.

(6) A cyclic change of distinguished taphocoenoses reflects variability of habitat environments and significant ecological rearrangements during the Domanik time.

(7) The Ukhta segment of the Timan–Pechora basin with the Domanik-type sedimentation represented a separate ecological zone of the outer shelf, where the depth range was 100–200 m, and this confirms a hypothesis of the shallow Paleozoic seas.

Collections of radiolarians (no. FF-P001), acritarchs (no. FF-P002), sponge spicules (no. FF-P003), and tentaculitids (no. FF-P004) are stored at the Federal Repository of Core Material from Petroliferous Provinces of Russia along with paleontological and lithological collections, the City of Aprelevka.

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REFERENCES

Afanasieva, M.S., *Atlas radiolyarii paleozoya Russkoi platformy* (Atlas of Paleozoic Radiolarians from the Russian Platform), Moscow: Nauchnyi Mir, 2000b.

Afanasieva, M.S., Adaptive Radiation of Radiolarians at the Devonian Stage of the Russian Patform Evolution, *Geol., Geofiz. i Razrabotka Neftyanykh Mestorozhd.*, 2000a, no. 12, pp. 7–14.

Afanasieva, M.S., Biostratigraphic Significance of Early Frasnian Radiolarians, *Eight Meeting of the International Association of Radiolarian Paleontologists (INTERRAD VIII). Paris*, Abstracts, 1997, p. 3.

Afanasieva, M.S., Biostratigraphich Significance of the Early Frasnian Radiolarians, *Dokl. Akad. Nauk*, 1997, vol. 355, no. 2, pp. 217–222.

Afanasieva, M.S., Biotic Crises of Ragiolarians in the Devonian History of the Russian Platform Evolution, *Biostratigrafiya i ekologo-biosfernye aspekty paleontologii. Tezisy dokladov XLIV sessii Paleontologicheskogo obshchestva* (Biostratigraphy and Ecological Biospheric Aspects of the Paleontology. Abstracts of Papers of XLIV Session of Paleontologic Society), St. Petersburg: Vses. Geol. Inst., 1998, pp. 8–9.

Afanasieva, M.S., Late Paleozoic Radiolarians of Karachaganak Deposits and Their Facies Confinement, *Stratigrafiya i paleontologiya Prikaspiiskoi vpadiny* (Stratigraphy and Paleontology of the circum-Caspian Depression), Moscow: Vses. Nauchno-Issled. Geologorazved. Inst., 1987, pp. 26–47.

Afanasieva, M.S., New Radiolaria of Orders Aculearia and Sphaerellaria from the Upper Devonian of Timan–Pechora Province in Russia, *Paleontol. Zh.*, 2000, no. 4, pp. 3–19.

Afanasieva, M.S., New Radiolarians of Superfamily Entactinoidea from the Upper Devonian of Timan–Pechora Province in Russia, *Paleontol. Zh.*, 2000, no. 2, pp. 20–33.

Afanasieva, M.S., New Variant of Systematics of the Paleozoic Radiolarians, *Geologiya i mineral'nye resursy evropeiskogo severo-vostoka Rossii: novye rezul'taty i novye perspektivy. Materialy XIII Geologicheskogo s"ezda Respubliki Komi* (Geology and Mineral Resources of the Northeastern European Russia: New Results and New Prospects. Materials from XIII Geological Meeting of Komi Republic), Syktyvkar: Inst. Geol. Komi Nauchn. Tsentr Ural. Otd. Ross. Akad. Nauk, 1999, pp. 253–256.

Afanasieva, M.S., Radiolarian Biotic Crisis in Devonian History of Russian Platform, *The 6th Zonenshain Conference on Plate Tectonics, Abstracts*, Moscow, 1998, p. 149.

Afanasieva, M.S., Radiolarians of Domanik (Early Frasnian) and Their Biostratigraphic Significance, *Desyatyi seminar po radiolyariyam. Tezisy dokladov* (Tenth Seminar on Radiolarians. Abstracts of Papers), Moscow: Inst. Litosfery Ross. Akad. Nauk, 1996, pp. 11–12.

Afanasieva, M.S., Some Features of the Early Frasnian Domanik Radiolarian Subassemblages in Southern Timan–Pechora Basin, *Chteniya pamyati S.V.Semikhatovoi. Novye dannye po biostratigrafii paleozoya Russkoi platformy i skladchatykh oblastei Urala i Tyan'-Shanya. Tez. dokladov* (Readings in Memory of S.V. Semikhatova. New Data on Paleozoic Stratigraphy in the Russsian Platform and Fold Regions of the Urals and Tien Shan. Abstracts of Papers), Moscow: Vses. Nauchno-Issled. Geologorazved. Inst., 1994, pp. 9–11.

Afanasieva, M.S. and Aitchison, J., Biostratigraphy of the Frasnian Stage by Radiolaria Evidence, *Stratigr. Geol. Korrelyatsiya*, 2001, vol. 9, no. 1.

Afanasieva M.S. and Mikhailova M.V., Domanik Radiolarians as Bioindicators of Sedimentation Conditions, *Seventh Meeting of the International Association of Radiolarian Paleontologists (INTERRAD VII), Abstracts*, Osaka, 1994, p. 3.

Afanasieva, M.S. and Mikhailova, M.V., Domanik Radiolarians and Their Importance to the Ukhta Paleobasin Reconstruction (Late Devonian, Timan-Pechora Basin, Russia), *5th Zonenshain Conference on Plate Tectonics, Abstracts*, Moscow, 1995a, pp. 195–196.

Afanasieva, M.S. and Mikhailova, M.V., Paleoecology of Domanic Radiolarians in SouthernTiman–Pechora Basin, *Ekosistemnye perestroiki i evolyutsiya biosfery* (Ecosystem Rearrangement and Evolution of the Lithosphere), Moscow: Paleontol. Inst. Ross. Akad. Nauk, 1995b, issue 2, pp. 49–65.

Afanasieva, M.S. and Mikhailova, M.V., Cyclic Development of the Ukhta Paleobasin During the Domanik Time of the Early Frasnian, *Problemy noosfery i ekobudushchego* (Problems of the Noosphere and the Future Ecology), Moscow: Ross. Akad. Estesstv. Nauk, 1996, issue 1, pp. 218–223.

Afanasieva, M.S. and Mikhailova, M.V., Radiolarians As a Possible Source Organic Matter in Oil, *Geol. Nefti Gaza*, 1998, no. 1, pp. 12–21.

Afanasieva, M.S. and Mikhailova, M.V., Cyclic Sedimentation at the Domanik Stage of Timan–Pechora Basin Evolution, *Geol., Geofiz. Razrabotka Neftyanykh mestorozhd.*, 2000, no. 12, pp. 15–24.

Afanasieva, M.S. and Vishnevskaya, V.S., Radiolarians: Benthos and Plankton, *Paleontol. Zh.*, 1993a, no. 3, pp. 3–13.

Afanasieva, M.S. and Vishnevskaya, V.S., Radiolarians of the Past As Indicators of Evolution of Siliceous-Carbonate Sedimentation, *Litol. Polezn. Iskop.*, 1993b, no. 5, pp. 52–68.

Becker, R.T., House, M.R., and Kirchgasser, W.T., Devonian Goniatite Biostratigraphy and Timing of Facies Movements in the Frasnian of the Canning Basin, Western Australia, *Eds. Hailwood, E.A., Kidd, R.B., High Resolution Stratigraphy. Geol. Soc. Spec. Publ. no. 70*, 1993, pp. 293–321.

Belyaeva, N.V., Korzun, A.L., Stashkova, E.K., and Grin'ko, T.G., *Model' stroeniya verkhnedevonsko-turneiskogo kompleksa otlozhenii na severe Verkhnepechorskoi vpadiny. Ser. Nauchnye rekomendatsii—narodnomu khozyaistvu* (A Model of Structure of the Upper Devonian–Turnaisian Sedi-

ments in the North of Upper Pechora Basin. Ser. Scientific Recommendations for National Economy), Syktyvkar: Komi Nauch. Tsentr Ural. Otd. Ross. Akad. Nauk, 1992, issue 103.

Bykova, E.V., Devonian Foraminifers and Radiolarians of Volga-Urals Region and Central Devonian Field and Their Stratigraphic Significance, in Bykova, E.V. and Polenova, E.N., *Foraminifery, radiolyarii i ostrakody devona Volgo-Ural'skoi oblasti. Trudy Vses. Nauch.–Issled. Geol.–Razved. Inst.* (Devonian Foraminifera, Radiolarian, and Ostracodes in Volga–Urals Region. Proceedings of All-Union Research Institute), 1955, no. 87, pp. 5–189.

Chernyshev, F.N., Works in the Timan of 1889, *Izv. Geol. komiteta*, vol. 9, 1890, nos. 2, 3, pp. 41–84.

Efremova, G.D., Late Paleozoic Prasinophytes from Eastern and Southeastern Parts of the Russian Plate, *Stratigrafiya i paleontologiya Prikaspiiskoi vpadiny* (Stratigraphy and Paleontology of the North Caspian Basin), Moscow: Vses. Nauchno-Issled. Geologorazved. Inst., 1987, pp. 93–102.

Fishman, M.V., History of Geological Studies and Development of Geological Science in the Northeastern European Soviet Union, *Istoriya geologicheskikh issledovanii na evropeiskom Severo-Vostoke* (History of Geological Studies in the European North-East), Syktyvkar: Komi Nauch. Tsentr Ural. Otd. Akad. Nauk SSSR, 1991, pp. 10–19.

House, M.R., Menner, V.V., Ovnatanova, N.S., *et al.*, Mid-Paleozoic Anoxic, Eustatic and Reef Episodes in the Frasnian of the Timan and Pechora Area of Russia and Their Interpretation and Comparisons with Similar Developments in the Other Areas, *Geol. Soc. London* (in press).

Kalitskii, K.P. and Stoyanov, A.A., Research in the Ukhta Region, *Izv. Geol. kom-ta*, 1919, vol. 38, no. 1, pp. 78–84.

Kalitskii, K.P., Ukhta Region, *Neft. Slants. Khoz-vo*, 1921, nos. 9–12, pp. 115–128.

Kaptarenko-Chernousova, O.K., *Kievskii yarus i elementy ego paleogeografii. Tr. Instituta geologicheskikh nauk. Ser. stratigrafii i paleontologii* (The Kiev Stage and Elements of Its Paleogeography. Proceedings of Institute of Geological Sciences. Ser. Stratigraphy and Paleontology), Kiev: Akad. Nauk USSR, 1951, issue 3.

Keizerling, A.A., Geognostic Notes along the Syas' River Banks, *Gorn. Zh.*, 1843, no. 9, part. III, Kn. IX, pp. 430–432.

Keyserling, A.A. and Krusenshteyn, P.I., *Wissenschaftliche Beobachtungen auf einer Reise in das Petschora Land im Jahre*, 1843, St.-Petersburg, 1846.

Khabakov, A.V., On Radiolarian Fauna Found in Paleozoic Siliceous Schists and Jaspers of the Caucasus Range and Its Paleogeographic Significance, *Izv. Vses. Geol.-Razved. Ob"ed.*, 1932, vol. 51, issue 12, pp. 219–225.

Khvorova, I.V. and Dmitrik, A.L., *Mikrostruktury kremnistykh porod* (Microtextures of Siliceous Rocks), Moscow: Nauka, 1972.

Klevtsova, A.A. and Afanasieva, M.S., Rifting, Radiolarians and Oil-and-Gas Potential of Russian Platform, *6th Zonenshain Conference on Plate Tectonics, Programme, Abstracts* 1998, pp. 161–162.

Klevtsova, A.A., Afanasieva, M.S., and Miletenko, N.V., Aulacogens and Oil-and-Gas Resources of the Russian Platform, *Novye idei v geologii i geokhimii nefti i gaza. Materialy Vtoroi mezhdunarodnoi konferentsii* (New Ideas in Geology and Geochemistry of Oil and Gas. Materials from the 2nd International Conference), Moscow: Moscow State Univ., 1998, pp. 101–103.

Koltun, V.M., Spicules of Siliceous Sponges from Upper Cretaceous Sediments of Transurals and from Paleogene Deposits of Northern Urals, *Paleontol. Zh.*, 1961, no. 1, pp. 61–69.

Kruglikova, S.B., Structure of Polycystine Radiolarians at the Species and Superspecies Levels and Paleoenvironments, *Sovremennyi i iskopaemyi mikroplankton Mirovogo okeana* (Recent and Fossil Microplankton), Moscow: Nauka, 1995, pp. 76–89.

Kruglikova, S.B., To the Relations of Radiolaria High-Rank Taxa as an Indicator of Paleoenvironment, *L.P. Zonenshain Memorial Conference on Plate Tectonics, Abstracts*, Moscow, 1993, p. 89.

Kushnareva, T.I., Stratigraphy, Lithology, and Oil-and-Gas Resources of Oil-Producing Devonian Sediments, *Geologiya i neftenosnost' Timano-Pechorskoi oblasti* (Geology and Oil Resources of Timan-Pechora Region), Leningrad: Gostoptekhizdat, 1959, pp. 81–93.

Kushnareva, T.I., Domanik Facies of the Middle Frasnian Basin in the Timan-Pechora Province, *Izv. Vyssh. Uchebn. Zaved., Ser. Geol. Razved.*, 1963, no. 3, pp. 46–54.

Kushnareva, T.I., History of Development of the Domanik Depression in the Timan-Pechora Province, *Litologiya i paleogeografiya paleozoiskikh otlozhenii Russkoi platformy* (Lithology and Paleogeography of the Paleozoic Sediments of the Russian Platform), Moscow: Nauka, 1972, pp. 125–128.

Kushnareva, T.I., Khalymbadzha, V.G., and Busygina, Yu.N., Biostratigraphic Zonation of the Domanik Formation in the Stratotype Section, *Sov. Geol.*, 1978, no. 1, pp. 60–71.

Kuz'min, A.V., Yatskov, S.V., Orlov, A.N., and Ivanov, A.O., The "Domanik Crisis" in Evolution of Fauna in the Frasnian Sea Basin of the Southern Timan (Northeastern Russian Platform), *Paleontol. Zh.*, 1997, no. 3, pp. 3–9.

Kuznetsov, A.V., Investigation History of Domanik Sediments in the Timan–Pechora and Volga–Ural Oil-and-Gas Basins, *Geologiya goryuchikh iskopaemykh evropeiskogo severa Rossii* (Geology of Fuel Minerals in the European Northern Russia), Syktyvkar: Komi Nauch. Tsentr, Ural. Otd. Ross. Akad. Nauk, 1995, pp. 90–105.

Maksimova, S.V., *Ekologo-fatsial'nye osobennosti i usloviya obrazovaniya domanika* (Ecologic Facies and Accumulation Conditions of the Domanik Formation), Moscow: Nauka, 1970.

Maksimova, S.V., The Rock-Forming Function of Siliceous Organisms and Volcanism, *Izv. Vyssh Uchebn. Zaved Ser. Geol. Razved.*, 1975, no. 5, pp. 22–27.

Menner, V.Vl., Arkhangel'skaya, A.D., Kuz'min, A.V., *et al.*, Correlation of Different-Facies Sections of the Frasnian Stage in the Southern Timan, *Byul. Mosk. O–va Ispyt. Prir., Otd. Geol.*, 1992, vol. 67, issue 6, pp. 64–82.

Menner, V.Vl., Mikhailova, M.V., Baranova, A.V., and Shuvalova, G.A., Paleoecological Siystems of the Upper Devonian Reefs and Banks in the Timan–Pechora Province, *Evolyutsiya ekosistem. Mezhdunarodnyi simpozium. Tez. dokladov* (Evolution of Ecosystems. International Symposium. Abstracts of Papers), Moscow: Paleontol. Inst. Ross. Akad. Nauk, 1995, pp. 83–84.

Murchison, R.J., de Verneuil, E., and von Keyserling, A., The Geology of Russia in Europe and the Ural Mountains, *Geology*, London: J.Murray, Allermarie street, 1845, vol. 1.

Nalivkin, D.V., *Uchenie o fatsiyakh* (Theory of Facies), Moscow: Akad. Nauk SSSR, 1955, vol. 1, 1956, vol. 2.

Nazarov, B.B. and Ormiston, A.R., Upper Devonian (Frasnian) Radiolarian Fauna from the Gogo Formation, Western Australia, *Micropaleontology*, 1983, vol. 29, no. 4, pp. 454–466.

Petrushevskaya, M.G., *Radiolyarii otryada Nassellaria Mirovogo okeana (Opredelitel' po faune SSSR)* (Radiolarians of the Order Nassellaria in the World Ocean: Identification Guide to Fauna of the Soviet Union), Leningrad: Zool. Inst. Akad. Nauk SSSR, 1981.

Petrushevskaya, M.G., *Radiolyarievyi analiz* (Analysis of Radiolarian), Leningrad: Nauka, 1986.

Strakhov, N.M., On Significance of Hydrosulfide Basins as Accumulation Regions of Bituminous and "Oil-Producing" Formations, *Izv. Akad. Nauk SSSR, Ser.Geol.*, 1937, no. 5, pp. 893–917.

Strakhov, N.M., Domanik Facies of the Southern Urals, *Tr. Inst. Geol. Nauk, Geol. Ser.*, 1939, issue 16, no. 6, pp. 1–122.

Tel'nova, O.P., Marine Phytoplankton from Devonian Sediments of the Timan-Pechora Province, *Ekostratigrafiya i iskopaemye soobshchestva paleozoya i mezozoya evropeiskogo Severo-Vostoka* (Ecostratigraphy and Fossil Communities of Paleozoic and Mesozoic of Northeastern Europe), Syktyvkar: Komi Nauch. Tsentr Ural. Otd. Ros. Akad. Nauk, 1995, issue 86, pp. 21–27.

Tikhii, V.N., Devonian Period: Paleogeography, *Paleogeografiya SSSR. Ob"yasnitel'naya zapiska k Atlasu litologo-paleogeograficheskikh kart SSSR. T. 2. Devonskii, kamennougol'nyi, permskii periody* (Paleogeography of the Soviet Union. Explanatory Note to the Atlas of Lithological–Paleogeographical Maps of the Soviet Union: vol. 2: Devonian, Carboniferous, and Permian Periods), Moscow: Nedra, 1975, pp. 12–40.

Tikhomirov, S.V., The Devonian of the Central Timan, *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1948, no. 2, pp. 47–56.

Tikhomirov, S.V., *Etapy osadkonakopleniya devona Russkoi platformy* (Stages of Devonian Sedimentation in the Russian Platform), Moscow: Nedra, 1967.

Tikhomirov, S.V., Factors and Basic Law of Sedimentation, *Izv. Vyssh. Ucheb. Zaved., Ser. Geol. Razved.*, 1972, no. 3, pp. 3–35.

Tikhomirov, S.V., Study of Eustatic Sea-Level Oscillations in the Russian Platform, *Evstaticheskie kolebaniya urovnya Mirovogo okeana v devone. Tez. dokladov* (Eustatic Sea-Level Oscillations during the Devonian), Moscow: Paleontol. Inst. Ross. Akad. Nauk, 1994, p. 44.

Tikhomirov, S.V., *Etapy osadkonakopleniya devona Russkoi platformy i obshchie voprosy razvitiya i stroeniya stratisfery* (Stages of Devonian Sedimentation in the Russian Platform and General Problems of the Stratisphere Evolution), Moscow: Nedra, 1995.

Tikhomirov, V.V., *Geologiya v Rossii pervoi poloviny 19 veka. Chast' 1* (Geology in Russia of the First Half of the 19th Century), Moscow: Akad. Nauk SSSR, 1960.

Tikhonovich, N.N., Materials from the Ukhta Geological Expedition 1929–1930, *Neft. Khoz.*, 1930, nos. 8, 9, pp. 1–20.

Tikhonovich, N.N., Structural Features of the Timan-Urals Province, *Sov. Geol.*, 1941, no. 1, pp. 43–60.

Timofeev, P.P. and Kholodov, V.N., Evolution of Sedimentation Basins in the Earth's History, *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1984, no. 7, pp. 10–34.

Vassoevich, N.B., Source Materials for Oil and Gas, *Proiskhozhdenie nefti i gaza i formirovanie ikh mestorozhdenii* (Origin of Oil and Gas and Formation of Their Fields), Moscow: Nedra, 1972, pp. 39–70.

Vishnevskaya, V.S., Merts, A.V., and Sedaeva, K.M., Devonian Radiolarians and Their Role in Oil Generation, *Dokl. Akad. Nauk*, 1993, vol. 333, no. 6, pp. 745–749.

Witsen, N., *Noord En Oost Tartarye, of te bond igh ontwerp*, Elsevier, 1692.

Yudina, Yu.A. and Moskalenko, M.N., Reference Sections of the Frasnian Stage in the Southern Timan, *Putevoditel' polevoi ekskursii* (Field Excursion Guide Book), Ukhta: TPO Vseross. Nauchno-Issled. Geol. Razved Inst., 1994.

Zav'yalov, V.A., *Geokhimiya i mikroelementy domanikovykh otlozhenii Yuzhnogo Pritiman'ya* (Geochemistry and Trace Elements of Domanik Sediments in Southern Timan Region), Moscow: Nauka, 1966.

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Upper Permian Stratigraphy of the Zhesi Honguer Area (North China)

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Abstract—Several tectonic blocks with Permian marine sequences of the different facies type are distinguished in the Zhesi Honguer area (North China). A brief characteristic of sequences and their correlation are considered. Three formation are established instead of previous two in the section of the Honguer Ola limestone ridge that is the reference one for the study area. Paleontological characteristics of different marine invertebrate groups from each formation are presented. The cold-water and warm-water characters of fauna are established respectively for the lower unit (Zhesi Formation) and for two formations (Lower and Upper Yihewusu) overlying it. Correlation with Permian sections in the Boreal realm and Paleotehys, as well as the analysis of brachiopod and fusulinid assemblages, indicate that the above formations are of the Kubergandian (Ufimian), Murgabian–early Midian, and Midian ages, respectively.

Key words: Upper Permian, biostratigraphy, biogeography, fusulinids, brachiopods, correlation, Paleotethys, Boreal realm.

INTRODUCTION

The Zhesi Honguer locality (Inner Mongolia, China) of marine invertebrates (Fig. 1) described by Grabau (1931) is well known because of a joint occurrence of cold- and warm-water faunas, mainly of brachiopods, in a single section. This allowed several paleogeographic and paleoclimatic conclusions to be inferred. Recently, the section attracted again a considerable attention of researchers, because of found fusulinids and rare conodonts, which significantly specify their age and enable correlation of poorly comparable stratigraphic scales of the Boreal realm and Paleotethys. Simultaneously, stratigraphic succession in this area is still interpreted ambiguously, or even controversially.

The main objective of this work was to decipher the intricate structure and Permian stratigraphy of the study area in order to clarify a succession of layers bearing different faunal groups. The work was organized by the Chanchun University of Science and Technology in cooperation with the Geological and Paleontological Institutes of the Russian Academy of Sciences. Ten days of field work allowed us to study of the Zhesi Honguer and several neighboring sections.

In addition to paleontological samples obtained during our field works, we also investigated materials collected in previous years and stored in the Chanchun University. These materials include a reach brachiopod collection by Liu Fa who studied it together with G. Waterhouse (New Zealand). Collection of corals was sampled by Lin Jing-dang. We took into consideration as well the data published by scientists from the Tianjin Institute of Geology and Mineral Resources (Ding Yunjie *et al.*, 1984). Fusulinids, brachiopods, bryozoans, and corals were determined by E.Ya. Leven, T.A. Grunt, I.P. Morozova (Paleontological Institute, RAS), and Lin Jing-dang, respectively.

INVESTIGATION HISTORY

First data on Permian deposits in the study area were obtained by Ch. Berkley and Ph. Morris, the participants of the Central Asian expeditions of 1922, 1923, 1925. These materials were summarized in a large monograph by Grabau (1931). Most of described collections originate from the Zhesi Honguer locality. In the 1970–1980s, Permian deposits of this area were intensely studied by Chinese geologists during the geological survey carried out by the Geological Bureau of Nei Mongol with participation of researchers from the Canchun University, Tianjin Institute of Geology and Mineral Resources, and Shenyang Institute of Geology and Mineral Resources. The results of these studies are published in several articles (Li Liang-fang, 1980; Xia Guoying, 1981, 1982) and in the monograph by Ding Yuinjie *et al.* (1984). Authors of these publications proposed several substantially different interpretations concerning the Zhesi Honguer section, and first of all, its lower and upper boundaries. Some views on their position are antithetic. Nevertheless, Permian deposits

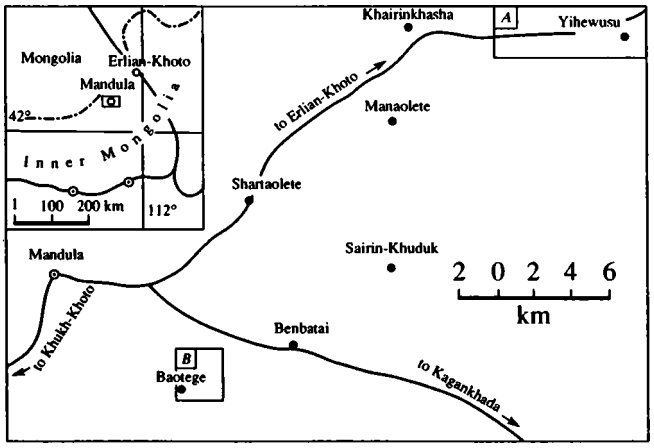

Fig. 1. Map of the studied Zhesi Honguer (*A*) and Baotege (*B*) areas.

were considered in all publication as forming a continuous succession only complicated by tectonic dislocations (Fig. 2). All researchers were also of unanimous opinion that all limestone exposures observed within the sandy–clayey sequence represent interbeds or lenses occurring *in situ*.

The variance of opinions concerning the section structure is also reflected in different interpretations of defined stratigraphic units, their number, and names. For instance, Grabau (1931) united all Permian sequences developed in the Zhesi Honguer area into the single Jisu Honguer Formation (Zhesi Honguer Formation in the modern transcription). According to this author, the middle part of the section corresponds to limestones of the Honguer Ola Ridge (Figs. 2, 3). They are underlain and overlain by thick terrigenous sequences, one of which rests with an angular unconformity and basal conglomerates upon the sequence of detrital rocks (graywackes) of unknown age in the northern part of the area under consideration.

In the article by Li Liang-fang, the entire Permian sequence from the Honguer Ola in the south to the northern wall of the Zhesi Honguer valley in the north is interpreted as a tilted homocline (Fig. 2). In opinion of this author, limestones of the Honguer Ola Ridge occupy the highest position in the section and are overturned. The northern part of the section is distinguished by Li Liang-fang (1980) as the autonomous Sanmianjing Formation.

According to interpretation by Ding Yinjie *et al.* (1984), Permian rocks of the Zhesi Honguer area form several folds that repeatedly exhibit the facies-variable Zhesi and Yihewusu formations (Fig. 2). At the base of the section, these authors distinguished in addition the Hugete Formation underlying the Zhesi Formation.

The above discrepancies in interpretation of the Zhesi Honguer section reflect contradiction between its seemingly simple structure with a homoclinal bed attitude and the irregular distribution of different-age organic remains. Accordingly, the section structure has been postulated to be more intricate that it actually is. Simultaneously, the region is insufficiently exposed that leads to a multitude of interpretations and complicates reconstruction of the true rock succession here.

CHARACTERISTICS OF SECTIONS

Exposures in the study area are mostly composed of clayey-detrital rocks with scarce organic remains. Fossils are confined in general to limy lenses and blocks irregularly distributed within the main rock mass. Only the Honguer Ola Ridge section is completely composed of limestones bearing the diverse fauna. We studied these rocks in two areas: Zhesi Honguer (A) and Baotege (B) (Fig. 1).

Zhesi Honguer Area

This area corresponds to that described by Grabau (1931, p. 34, Fig. 3 in this article). Its southern part is occupied by the low and elongated Honguer Ola Ridge composed of limestones dipping northward at the angles of 30°–40°. We studied exactly the same section that was described by Grabau (1931, Exposures 1200, 1205–1209) (Fig. 4). The following members are exposed here in a distinctly continuous stratigraphic succession (from the base upward):

(1) Light gray bedded bioclastic limestones with brachiopod coquina interbeds and lenses: their detrital fraction consists of fragments of crinoids, bryozoans, spines and valves of brachiopods *Kochiproductus* cf. *porrectus* (Kutorga), *Liosotella decimana* Man., *Anidanthus* sp., *Waagenoconcha* sp., *Spiriferella* sp., and *Neospirifer* sp. Also present are solitary corals and minute suppressed foraminifers. Locally, rhythmical patterns in alternation of coarse- and fine-grained limestones have been observed. Rhythms are separated from each other by distinct erosional surfaces. It is well seen that concavities are filled with a relatively coarse detrital material gradually decreasing in size upward. Such relationships between rhythmically alternating beds excludes their overturned position. The apparent thickness of limestones exposed at the base of the slope is 10 m. Underlying strata are unexposed.

(2) Bioclastic limestones; these rocks are darker in color and yield abundant brachiopods *Waagenoconcha sinuata* Lee et Gu, *Kochiproductus maximus* Man., *K. saraneanus* Fred., *K.* cf. *porrectus* (Kutorga), *Liosotella decimana* Man., *Anidanthus graciosus* (Lee et Gu), *Yakovlevia* aff. *mammatiformis* (Fred.), *Y. spinosa* Duan et Li, *Linoproductus rhiphaeus* (Stepanov), *Marginigfera gobiensis* Chao, *M. leptorugosa* Duan et Li, *Spiriferella magna* Fred., *S. salteri* (Tschern.), *S. voluta* Duan et Li, *Rhombospirifer zhesiensis* Duan et Li, *Gypospirifer volatilis* Duan et Gu, *Alispiriferella* sp., and *Stenoscisma* sp. nov. Inside limestones, there is an intercalated diabase body (sill) 0.5 m thick. The total thickness is 9 m.

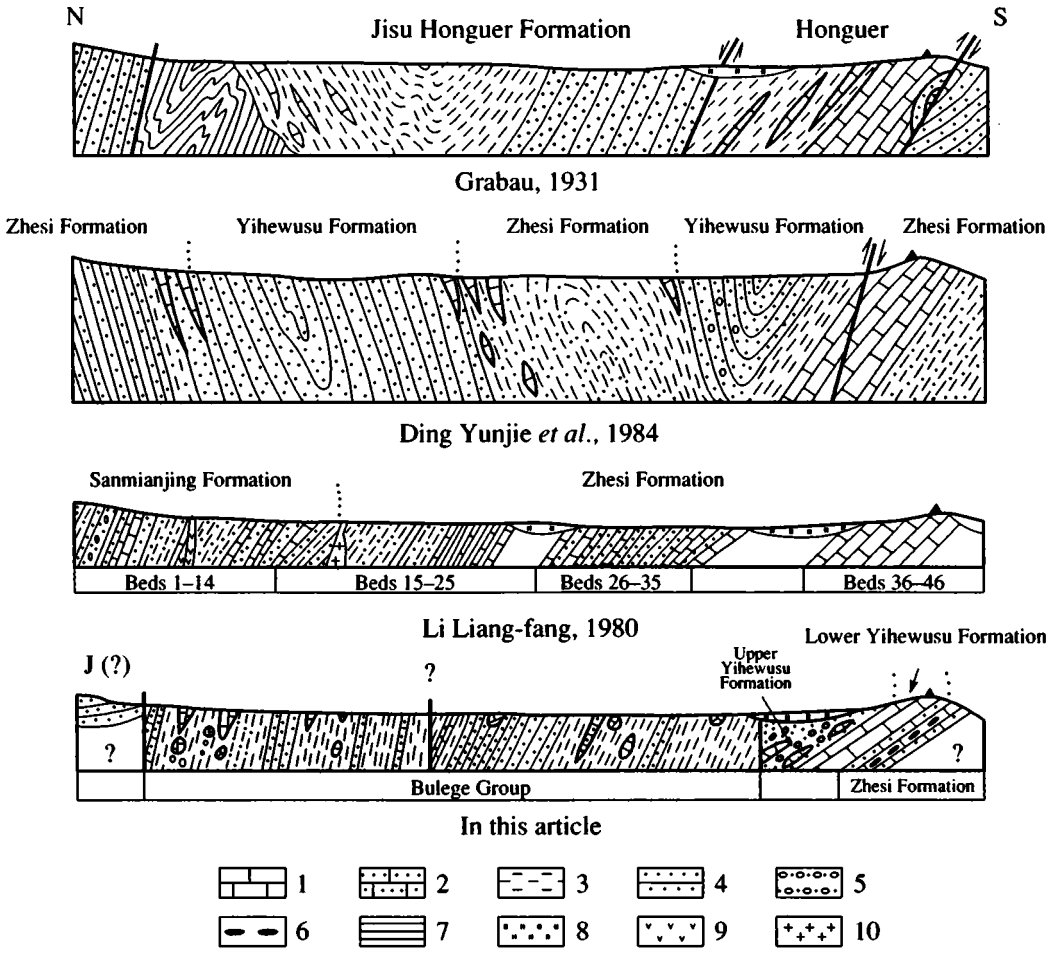

Fig. 2. Different interpretations of the Permian section structure in the Zhesi Honguer area: (1) biohermal limestone; (2) detrital limestone; (3) shale, siltstone; (4) sandstone; (5) conglomerate; (6) chert; (7) graywacke; (8) Quaternary sediments; (9) diabase; (10) quartz porphyry.

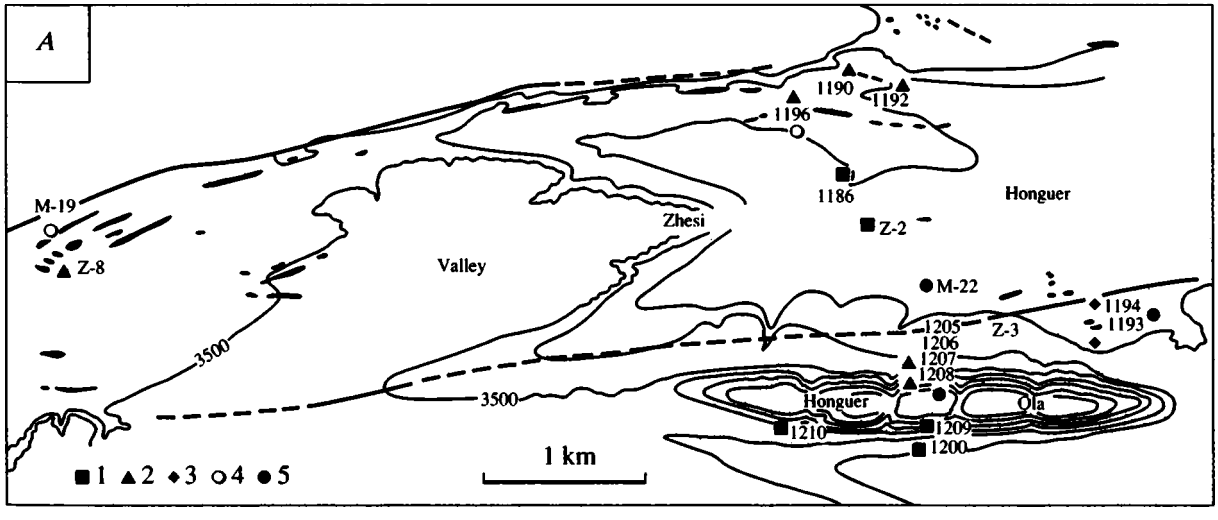

Fig. 3. Detailed map of the Zhesi Honguer area (*A* in Fig. 1; after Grabau, 1931 with additions) and sampling points of fusulinid and brachiopods assemblages: (1) *Spiriferella–Kochiproductus–Yakovlevia*, (2) *Enteletes–Streptorhynchus–Richthofenia*, (3) *Haydenella*, (4) *Pseudofusulina*, (5) *Codonofusiella*.

Numbers 1190–1210 denote sampling points of the Central Asian Expedition (Grabau, 1931); symbols Z-2, Z-3, Z-8, M-19, and M-22 indicate our sampling points. Solid and dotted lines designate proven and inferable faults, respectively.

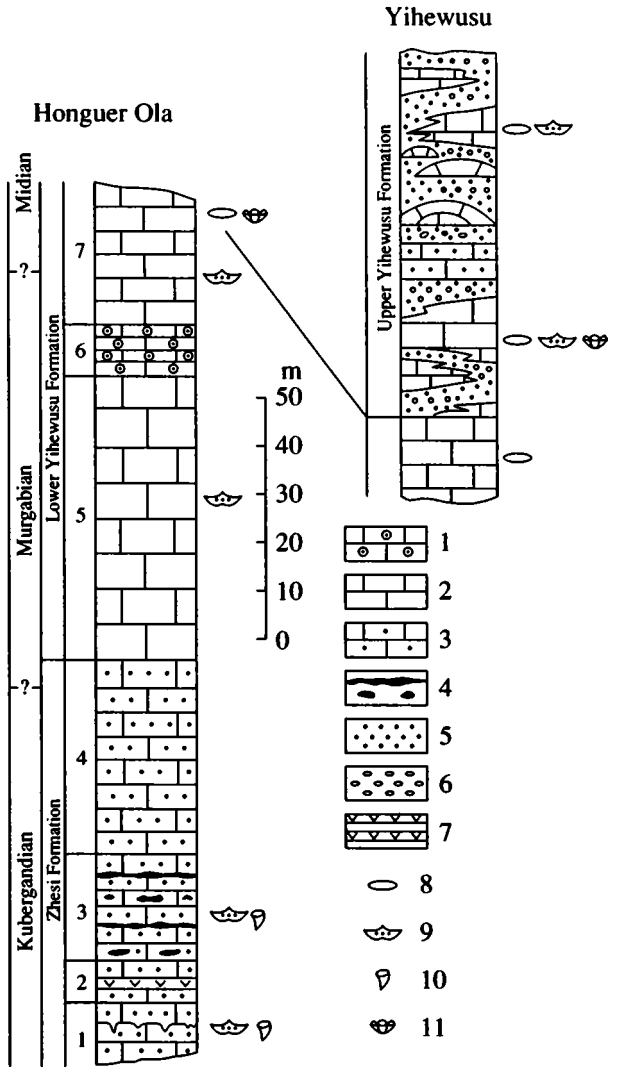

Fig. 4. The Honguer Ola section: (1) crinoid, (2) biohermal, and (3) bioclastic limestones; (4) cherty interbeds; (5) sandstone; (6) conglomerate; (7) basalt dike; (8) fusulinids; (9) brachiopods; (10) solitary and (11) colonial corals. Numbers to the left of the column correspond to numbers of beds described in the text.

(3) Dark gray bioclastic limestones with lenses and nodules of cherts; like in underlying strata, their clastic material mainly consists of fragments of crinoids, brachiopods, and bryozoans. Present in the rocks are smaller foraminifers, brachiopods *Yakovlevia* aff. *mammatiformis* (Fred.), *Anidanthus graciosus* (Lee et Gu), *Rhombospirifer zhesiensis* Duan et Li, *Spiriferella salteri* (Tschern.), and *Stenoscisma* sp. nov., and corals. The thickness is 22 m.

(4) Light gray thick-bedded to massive, crinoid–detrital limestones with rare undeterminable brachiopod, coral, and bryozoan remains. The thickness is 40 m.

(5) Light gray to pinkish, mostly massive, less commonly thick-bedded and locally brecciated biomicrites with abundant organic remains; most common among the latter are bryozoans and hydrozoans locally forming small bioherms. Also present are rugose corals, rare undeterminable brachiopods remains, crinoids, and algae of the genus *Tubiphites*. The thickness is 60 m.

(6) Black medium-bedded limestones overfilled with large crinoid columnals; the rocks wedge out soon along the strike. The thickness is 10 m.

(7) Limestones almost identical to, though darker than those of Bed 5; an upper part of the member yield smaller foraminifers, fusulinids, corals, and brachiopods *Orthotichia* sp., *Enteletes andrewsi* Grabau, *Echinauris jisuensis* (Chao), *Martinia osborni* Grabau, *M. sinensis* Grabau, *Hemiptychina morrisi* Grabau. The apparent thickness is 30–40 m.

Northward of limestones composing Member 7, there are shales with siltstone and sandstone interbeds exposed along the section line. The contact between these rock varieties is hidden under Quaternary sediments. We suggest the tectonic origin of the contact, because shales dip at an angle of 70°–80°, in contrast to almost horizontal attitude of limestones of the Honguer Ola Ridge, although in the same northern direction.

Near the Yihewusu Well located in the northeastern extremity of the ridge (Fig. 3, points Z-3 and M-22) it can be seen that limestone beds composing Member 7 are disintegrated into separate small lenses, spaces between which are filled with sandstones and conglomerates. Limestones are either similar to those of Member 7, or correspond to bioclastic varieties. They enclose abundant brachiopods and corals in the first case, and fusulinids in the second. Fusulinids were found as well in sandstone beds.

Collections by Grabau (1931; point 1193, point 1194) and by Chinese paleontologists (Ding Yunjie *et al.*, 1984; Section I, Beds 14–16) originate from the considered area as well. The approximate thickness of the rock sequence is about 100 m. Relationships between the considered part of the section and sandstone–shale beds exposed northerly are unclear because of poor exposition. It can be assumed that the contact in question is of the tectonic type.

The described section is distinctly divisible into three formations. The lower formation (Fig. 4; the Honguer Ola section, Beds 1–4) is composed of well-bedded bioclastic limestones, the middle one (Fig. 4; the Honguer Ola section, Beds 5–7) corresponds to biomicrites, and the upper unit (Fig. 4; the Yihewusu section) is represented by sandstones and conglomerates with lenses of biomorphic and detrital limestones. In the monograph by Ding Yunjie *et al.* (1984), the lower one third of the section is referred, together with a thick sequence of terrigenous rocks, to the Zhesi Formation; its upper two thirds are attributed to the Yihewusu Formation. We propose to preserve the name Zhesi Formation only for the carbonate part of the sec-

tion (Fig. 4; the Honguer Ola section, Beds 1–4), because its stratigraphic occurrence above the terrigenous rocks is not obvious and assumed by Chinese scientists who followed the viewpoint of Grabau. It is reasonable to subdivide the Yihewusu Formation into two units: the carbonate Lower Yihewusu (Fig. 4; the Honguer Ola section, Beds 5–7) and terrigenous–carbonate Upper Yihewusu (Fig. 4; the Yihewusu section) formations. In addition to lithological peculiarities, all three formations show their own paleontological characteristic.

The Zhesi Formation is characterized by relatively scarce organic remains. Brachiopods locally forming mass accumulations represent an exception.

Foraminifers are not numerous, represented by rare *Tuberitina* sp., *Nodosaria* sp., *Frondicularia* sp., *Geinitzina* (?) sp., *Hemigordius* sp., *Agathammina* sp., *Glomospira* sp., and *Endothyra* sp. Chinese researchers (Ding Yunjie *et al.*, 1984) reported also on occurrence of fusulinids *Pseudofusulina* sp.

Rare solitary rugose corals are subdivided into two assemblages. In addition to its index species, the lower *Tachylasma zhesiensis–Callophyllum sinense* assemblage includes *Paracaninia tzuchiangensis* (Huang), *Gerthia crassoseptata* Ding, *Ufimia* sp., and *Plerophyllum* sp. Ding Yunjie *et al.* (1984) reported also on finds of *Plerophyllum crassoseptatum* Ding, *P. neimongolensis* Ding, *P. calvatum* Iljina, *P. ephippiomorphum* Ding, *P. zhesiensis* Ding, and *Pentaphyllum* sp.

The upper *Paraduplophyllum multiplicatum–Lopholasma bellum* assemblage is represented by rare thin-walled forms. Its index species are accompanied by *Diphycarinophyllum baotegense* Ding, *Amplexocarinia miralis* Soshkina, and others.

Bryozoans are also not numerous and include *Dybowskiella* sp., *Dyscritella* sp., *Stenodiscus* sp., and *Girtypora* sp. occurring higher in the section as well. An integral *Spiriferella–Kochiproductus–Yakovlevia* assemblage of brachiopods (Ding Yunjie *et al.*, 1984) includes about 40 species of 17 genera. Most characteristic forms of the assemblage are *Orthotichia morganiana* (Derby), *Waagenoconcha sinuata* Lee et Gu, *W. angustata* Sarytch., *Kochiproductus maximus* Man., *K. saraneanus* Fred., *K. porrectus* (Kut.), *Liostella decimana* Man., *Anidanthus graciosus* (Lee et Gu), *Muirowoodia usualis* Duan et Li, *Yakovlevia mammatiformis* (Fred.), *Y. unsinuata* Duan et Li, *Y. spinosa* Duan et Li, *Linoproductus rhiphaeus* (Step.), *Marginifera leptorugosa* Duan et Li, various *Spiriferella* (*S. magna* Fred., *S. voluta* Duan et Li, *S. neimonggolensis* Duan et Li, *S. lita* Fred., and others), *Kaninospirifer adpressum* Liu Fa et Waterhouse, *Rhombospirifer zhesiensis* Duan et Li, *Gypospirifer volatilis* Duan et Gu, *Alispiriferella hinganensis* Lee et Gu, and *Stenoscisma margaritovi* (Tschern.). This assemblage contains many forms in common with the Tsagan Ola brachiopod assemblage of the Dalan Ola–Lugingol structural zone of Southern Mongolia (*Permskie bespozvonochnye...*, 1991). Close taxonomic similarity between these assemblages is notable at both the generic and species levels. Based on several successive correlations, we determine, following authors of the above-mentioned monograph, the Late Permian (Ufimian) age of both assemblages. Our materials do not confirm opinion of Manankov (1999) who suggested the Ufimian–Kazanian (or Kubergandian–Murgabian) age of the *Spiriferella–Kochiproductus–Yakovlevia* assemblage that is characteristic of the main part of the Zhesi Formation. In more detail, this problem will be discussed below.

The Lower Yihewusu Formation significantly differs from the Zhesi Formation. Smaller foraminifers are still scarce here. Most characteristic amid them is *Baisalina* sp. missing from the underlying layers. The associated forms are *Glomospira* sp., *Globivalvulina* sp., *Nodosaria* sp., *Pachiphloia* cf. *langei* Sosnina.

Fusulinids appearing near the formation top are represented by *Boultonia (?)* sp., *Lantschichites (?)* sp., *Sichotenella maichensis* Sosnina, *Reichelina (?)* sp., *Codonofusiella* sp., *Pseudofusulina quasipactiruga* Xia, *P. kwangchiensis* Chen, *P. solita* (Skinner), and *P. grabaui* sp. nov. In addition, Ding Yunjie *et al.* (1984) reported on *Codonofusiella protolui* Xia, *C. pseudoextensa* Xia, *Pseudofusulina quasipactiruga* Xia, *P. trivialis* (Xia), "*P. normalis* (Xia)" [=*P. solita* (Skinner)], *P. arctica* (Xia), and "*P. neimongolensis* (Xia)" (=*Chusenella extensa* Skinner). The listed pseudofusulines and *Chusenella* forms are identical or very similar to those known from the vicinity of Ankara in Turkey (Skinner, 1969), where they occur together with typical Midian *Yabeina* and highly evolved *Neoschwagerina* forms. The Midian age of the considered assemblage is also supported by occurrence of *Codonofusiella, Reichelina, Lantschichites*, and *Sichotenella* species.

Abundant Rugosa corals belong to the *Waagenophyllum–Wentzelella* assemblage. Brachiopods occurring mainly in the upper part of the formation (Fig. 4; Honguer Ola section, Bed 7) are relatively scarce. According to definition by Ding *et al.* (1984), they represent the *Streptorhynchus–Hemiptychina–Richthofenia* assemblage consisting of *Enteletes andrewsi* Grabau, *Streptorhynchus subcataclinus* Duan et Li, *S. undulatus* Duan et Li, *Echinauris jisuensis* (Chao), *Waagenoconcha humboldti* (Orb.), *Cancrinella koninckiana* (Vern.), *Horridonia morrisi* (Chao), *Richthofenia cornuformis* Duan et Li, *Martinia osborni* Grabau, *M. sinensis* Grabau, and *Hemiptychina morrisi* Grabau. This group replaces the *Spiriferella–Kochiproductus–Yakovlevia* assemblage in a continuous section. Only some forms of genera *Waagenoconcha, Anidanthus, Spiriferella*, and *Stenoscisma* are species in common with the previous assemblage, in which they are abundant. In its taxonomic composition, the assemblage is highly endemic, characteristic of reefal communities. Nevertheless, it includes many forms of the Sozio Formation in Sicily. Simultaneously, the assem-

blage under consideration shows a significant taxonomic similarity with the brachiopod assemblage from exotic blocks of the Crimea Mountains. The last two localities exemplify deposits of the Murgabian Stage. Some taxons occurring in the Lower Yihewusu Formation are also known from the Vargal Formation of the Salt Range and Maokou Formation of South China. Thus, brachiopods suggest the Murgabian–early Midian age of the Lower Yihewusu Formation that corresponds, more or less, to the dating based on fusulinids. Since both fusulinids and brachiopods occur in the upper part of the formation, it can be assumed that the greater part of the latter is of the Murgabian age.

In terms of paleontological characteristic, the Upper Yihewusu Formation is only slightly different from the underlying unit. Fusulinids in our collection, which are sampled from several limestone lenses (bioherms?), are represented by *Pseudofusulina kwangchiensis* (Chen), *P. solita* (Skinner), *P.* cf. *splendens* (Skinner), *P. trivialis* (Xia), and *P.* sp. nov. This fusulinid assemblage differs from that occurring in the uppermost Lower Yihewusu Formation only in the lower diversity.

Corals represent the *Waagenophyllum–Wentzelella* assemblage characteristic of the uppermost Lower Yihewusu Formation, but they are slightly more diverse. Most abundant are colonial *Waagenophyllum virgalense mongoliense* (Grabau), *W. indicum* Waagen, and *Wentzelella damaoqiensis* Ding. They coexist with solitary *Pseudowaagenophyllum vesiculosum* Ding, *Productiophyllum wumengensis* (Ding), *Paraduplophyllum oppositum* Fedor., *Duplocarinia* sp., *Tetralasma cylindrica* (Grabau), *Diphycarinophyllum baotegense* Ding, and others.

The brachiopod assemblage from the Upper Yihewusu Formation is impoverished. Present are only single *Streptorhynchus* forms, *Haydenella kiangsiensis*, rare terebratulids and rhynchonellids, the occurrence of which does not deny the Midian age of the formation.

North of the Honguer Ola Ridge, there is the wide and flat Zhesi Honguer valley (Fig. 3) overlain by a thin cover of Quaternary sediments. Bedrocks are represented by sandstones and shales with less common, thin interbeds of sandy–detrital limestones. They enclose separate isometric bodies of biohermal limestones several meters across. Host rocks dip northward at the high angles (70°–90°). Small-scale folds and faults are locally observable. It is impossible to judge about the deformation style of these deposits, because they are poorly exposed. Rhythmically alternating shales, sandstones, and detrital limestones are exposed in the middle part of the valley. Structural relationships between their layers dipping northward at high angles distinctly indicate that they are overturned, and this allowed Li Liang-fang (1980) to interpret the entire Permian sequence, limestones of the Honguer Ola Ridge included, as overturned as well.

At the foot of hills fringing the northern part of the valley, there are lens-like or isometric bodies of biohermal limestones stretching chain-like along the strike of enclosing sandstones and shales. The associated interbeds up to several meters thick are composed of detrital and sandy–detrital limestones. Beds dip almost vertically, and position of their basal planes is unclear.

According to our observations, limestone bodies represent mostly (if not entirely) the allochthonous blocks. This is clearly seen in the northwestern part of the valley near the Bulege Well (Fig. 5), where the vertically dipping shales with thin sandstone and sandy–detrital limestone interbeds are exposed. In the north, they contact with thin-bedded clastic limestones. The contact is probably stratigraphic, although complicated by the fault. The argillite matrix encloses limy blocks of a variable size and configuration (Fig. 3, point Z-8). These are mostly composed of massive biomorphic or of bedded sandy–detrital limestones. Blocks are frequently bounded by conglomeratic breccias. The bedding in blocks, when visible, can cross that of enclosing rocks. One of the blocks consists of closely joined different rock varieties (sandstones, detrital and biomorphic limestones). A sharp fold of bedded sandstones is cut by block edges. All these facts indicate that rock blocks and fragments are redeposited. The assumption is valid for other limestone bodies embedded into terrigenous deposits of the valley north of the Honguer Ola Ridge.

The provenance and scale of block displacement are still unknown. In most cases, limestones of the blocks are similar to those of the Lower and, less commonly, of the Upper Yihewusu formations. In addition to lithological similarity, they yield similar faunal assemblages. Organic remains in blocks of bioclastic limestones are mostly represented by brachiopods. Although assemblages from separate blocks differ from each other, their taxonomic composition is rather uniform. In total, the assemblage includes over 50 species of 25 genera. The latter are *Enteletes, Orthotichia*, and *Schizophoria* from the Entelacea superfamily; *Streptorhynchus, Chelonina, Derbyella, Geyerella*, and *Meekella* from the Davidsoniacea superfamily; *Edriosteges, Marginifera, Spinomarginifera, Lamnimargus, Magniplicatina, Compressoproductus, Echinauris, Eolyttonia, Leptodus, Richthofenia*, and *Prorichthofenia* from the Productidae family; *Stenoscisma* and *Uncinunellina* from the Rhynchonellidae family; *Hustedia* and *Posicomta* from the Atiridídae family; *Squamularia, Martinia*, and *Spiriferinaella* from the Spiriferidae family; *Hemiptychina, Notothyris, Morrisina*, and *Mongolina* from the Terebratulidae family. This assemblage of typical warm-water type is characteristic of biohermal buildups, which were widespread along the northern periphery of the Paleotethys during the entire Permian period. As is determined, the assemblage is of the Murgabian age.

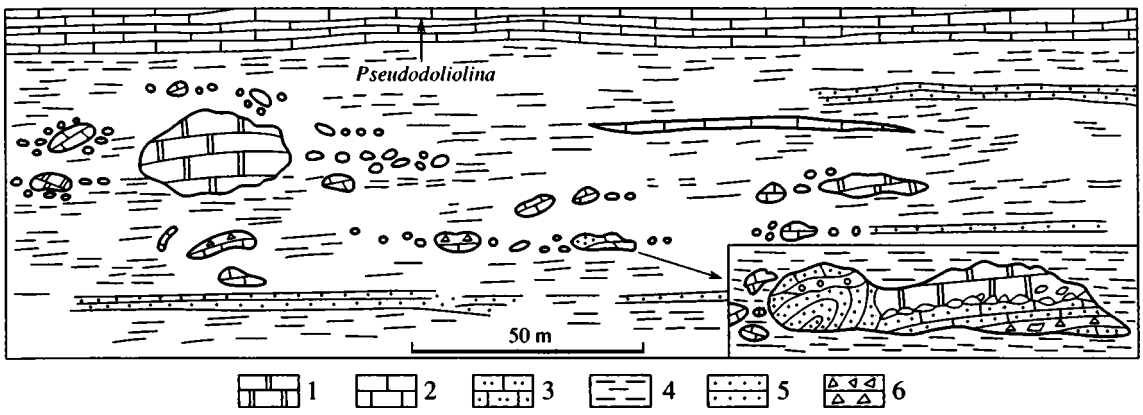

Fig. 5. Position of limestone blocks in terrigenous sequences of the Bulege Well area (plan view): (1) biohermal, (2) thin-bedded detrital, and (3) sandy–detrital limestones; (4) argillite; (5) sandstone; (6) conglobreccia (lens-like bodies of different configuration correspond to exposures of Upper Permian organogenic limestones).

According to the data available, the enclosing rocks are virtually identical in age to limestones proper. In several exposures, for instance, shales enclose thin limestone interbeds and lenses with brachiopods *Kochiproductus* sp., *Spiriferella* sp., and *Neospirifer* ex gr. *koargychanensis* Zavad. characteristic of the Zhesi Formation. Thin beds of detrital limestone alternating with shales and sandstones yield a bryozoan assemblage of *Dyscritella* sp., *Streblascopora* sp., *Hexagonella* sp., *Girtyporina* sp., *Rhabdomeson* sp., and *Dyscritellina* sp. The assemblage is similar to that from the Lower Yihewusu Formation and typical of the Chandalaz Formation of the Primor'e region, where it is attributed to the Midian Stage. Sandstones and bedded detrital limestones from the vicinity of the Bulege Well (Fig. 3; point M-19) contain fusulinids *Pseudodoliolina elongata* Choi coeval to fusulinids from the Lower and Upper Yihewusu formations. In the section of the Kitakami Mountains of Japan, this species coexists with *Codonofusiella* and *Rauserella* forms. *Lepidolina multiseptata* (Choi) appears immediately above their levels. This suggests that beds with *P. elongata* Choi cannot be older than the uppermost Murgabian beds, and, most likely, they are of the Midian age. Similar pseudodoliolines are also known from the Chandalaz Formation of the Primor'e region and from the uppermost Maokou Formation of China.

All these finds indicate that the thick sequence of shales and sandstones exposed in the valley is coeval in general to embedded limestone blocks and to the carbonate section of the Zhesi, Lower Yihewusu and Upper Yihewusu formations. Thus, it can be assumed that shales and sandstones of the Zhesi Honguer valley accumulated synchronously with limestones of the Honguer Ola Ridge. The terrigenous rocks filled up the relatively deep depression, the Bulege trough, as we term it, whereas limestones accumulated on the relatively stable Honguer Ola rise, from which separate blocks slid subsequently into the trough. In the contact zone between carbonate and terrigenous facies, all rock varieties can be partly intercalated (Fig. 6). The existence of two independent types of section—carbonate on the rise and terrigenous in the trough—makes it impossible to apply terms "Zhesi" and "Yihewusu" to the thick terrigenous sequence, as it is done in the work by Ding Yunjie *et al.* (1984). As long as this sequence remains undivided into separate formations, we propose to term it the Bulege Group. In general, the Bulege Group contains fossil assemblages similar to those from the carbonate section of the Zhesi Honguer Ridge. The group does not exhibit, however, a normal succession of fossils, because the latter are mainly confined to isolated bodies of carbonate rocks incidentally embedded into a thick sequence of detrital–clayey rocks. Irregular distribution patterns of faunal assemblages in the Bulege Group were usually interpreted as a result of intricate deformations. We believe that this can also be explained by the fact that most of limestone bodies represent redeposited blocks.

Thus, the following conclusion can be drawn:

(1) Limestones of the Honguer Ola Ridge and terrigenous Bulege Group cannot be considered as forming a continuous section. They accumulated synchronously, but under condition of a relatively stable tectonic regime and a rapid compensated subsidence, respectively.

(2) Most of limestone bodies embedded into the Bulege Group slid from the Honguer Ola Ridge.

Baotege Area

The Baotege area is located 30 km southwest of the Honguer Ola Ridge in the vicinity of the eponymous well. Ding Yunjie *et al.* (1984) referred some of detrital and carbonate sequences developed in this area to the Zhesi and Yihewusu formation, whereas other sequences were united into the older Hugete Formation. The entire section was interpreted as an overturned homocline dipping southward and complicated in the

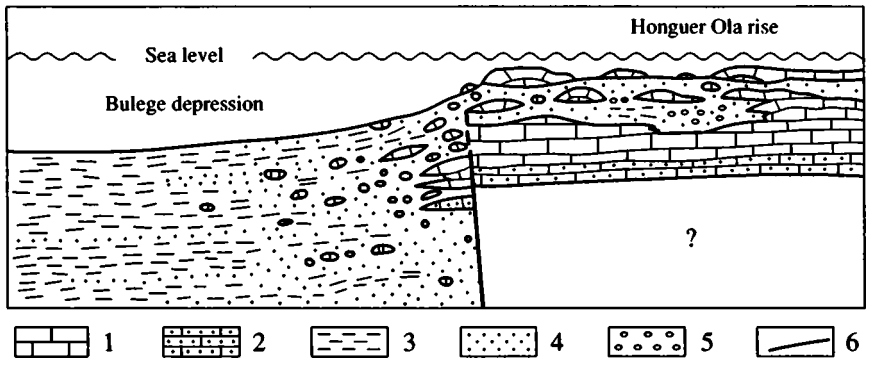

Fig. 6. Sketch of facies relationships between deposits of the Bulege trough and Honguer Ola Ridge: (1) biohermal and (2) detrital limestones; (3) argillite, siltstone; (4) sandstone; (5) conglomerate; (6) inferred fault (the fault plane dip is shown conditionally).

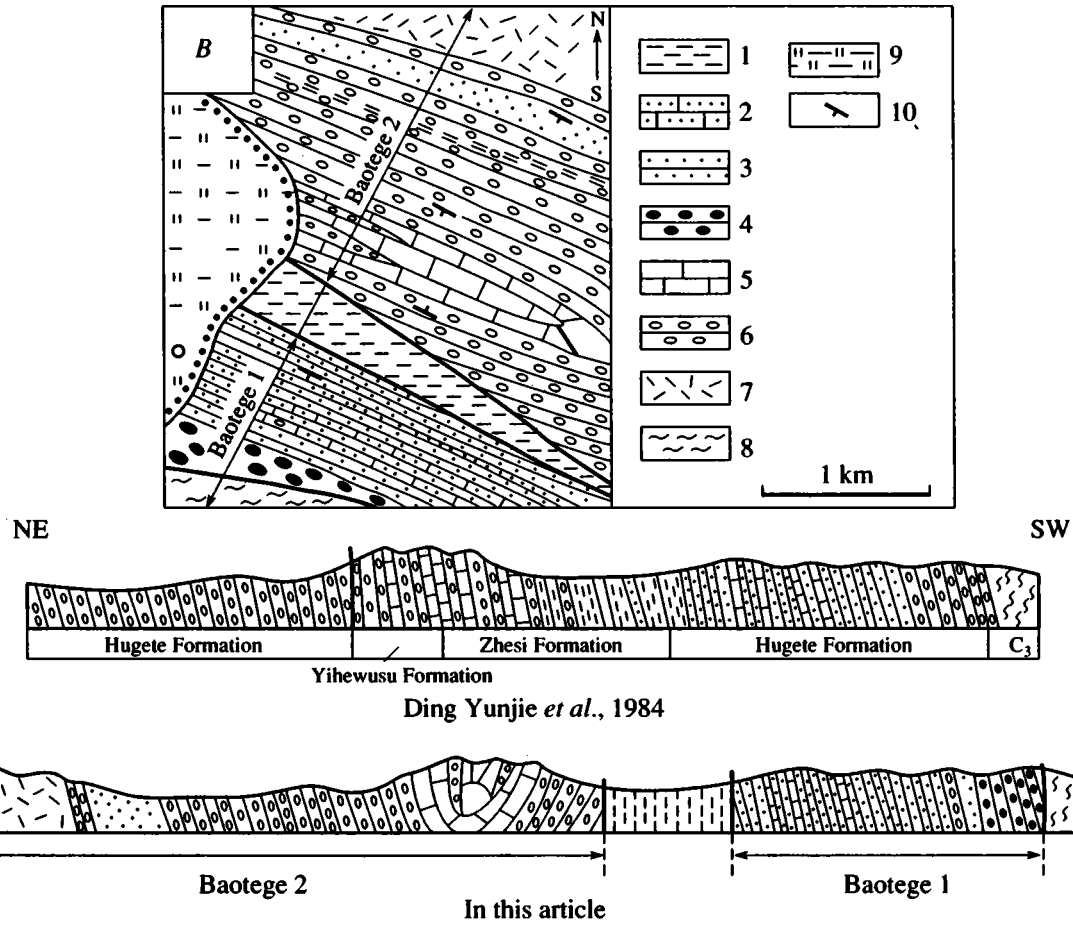

Fig. 7. Geological structure of the Baotege area (*B* in Fig. 1): (1) argillite; (2) sandy limestone; (3) sandstone; (4) conglomerate with limy pebbles; (5) biohermal limestone; (6) conglomerate with pebbles of acid volcanics; (7) volcanics; (8) gneiss; (9) Quaternary sediments; (10) direction of bed dip.

north by a fault, along which oldest and youngest Permian rocks are in contact (Fig. 7).

Our observations do not confirm the above interpretation. Like in the Zhesi Honguer area, we distinguished here at least two section types (Baotege 1 and Baotege 2), which partly overlap each other and the Zhesi Honguer section. They are separated by a fault zone, which encloses varicolored shales of unknown age.

The southern section (Fig. 8; Baotege 1) represents a homocline steeply dipping southward and bounded by faults in the north and south. The section that is sep-

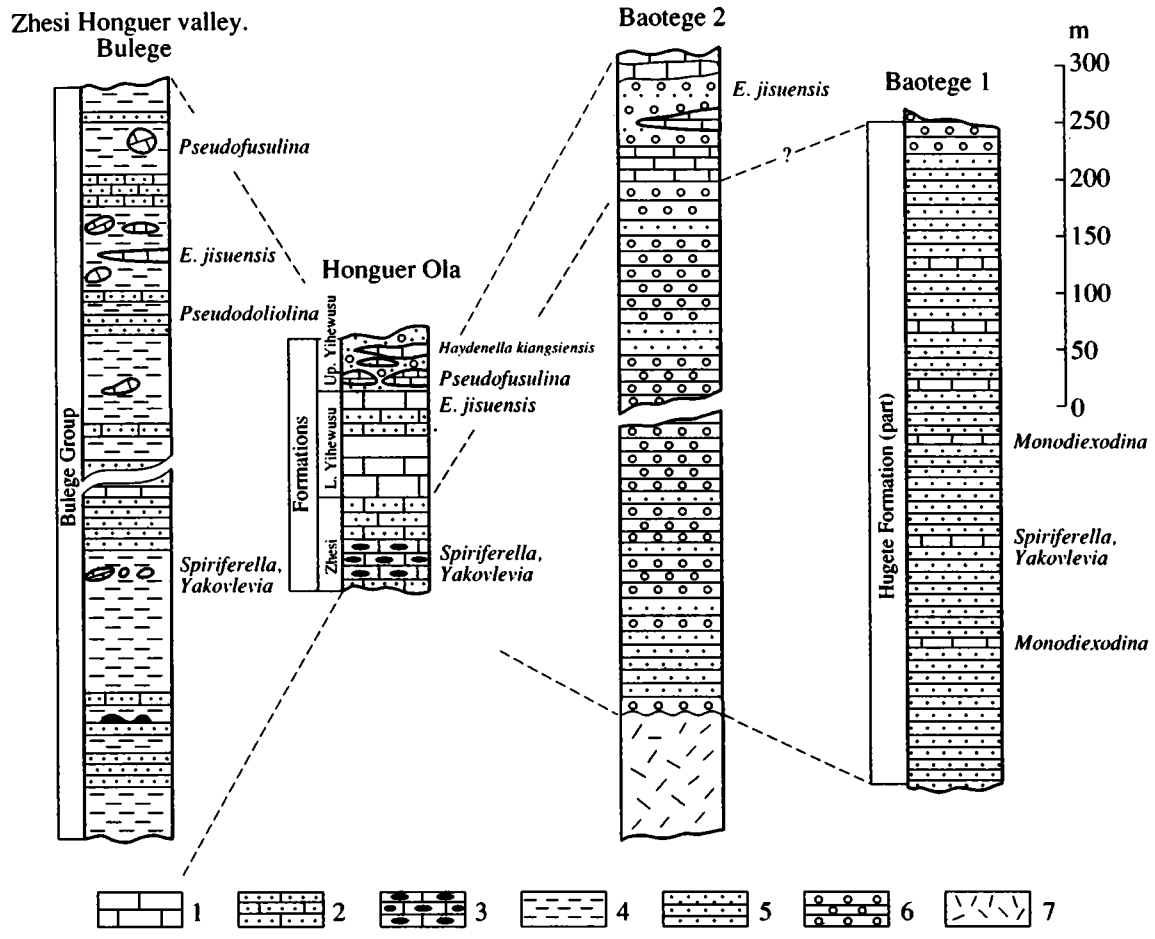

Fig. 8. Correlation of Permian section from the Zhesi Honguer and Baotege areas: (1) biohermal and (2) detrital limestones; (3) limestone with cherty concretions; (4) shale, siltstone; (5) sandstone; (6) conglomerate; (7) acid volcanics (as explained in the text, formations of the Baotege 2 section are shown unnamed).

arated by fault from varicolored shales located to the north includes the following members of strata steeply dipping southward:

(1) Brown–gray medium- to fine-grained quartz–feldspathic sandstones and siltstones with interbeds (up to 1 m thick) of black bioclastic, crinoid, and sandy limestones; peculiar are limestone interbeds with abundant and large crinoid columnals. Limy interbeds are mainly confined to the middle part of the member. They yield brachiopods *Paramarginifera leptorugosa* Lee et Gu, and *Yakovlevia unsinuata* Lee and Gu. Thin interbeds of sandy limestone, which are located at the same level and slightly higher, contain abundant fusulinids of the *Monodiexodina* genus. The apparent thickness is about 400–500 m.

(2) Coarse-grained polymictic sandstones and medium- to small-pebbled conglomerates; subangular pebbles are largely represented by sandstone, siltstone, argillite, and sometimes by quartz and limestone. Limestone pebbles yield fusulinids belonging to two different-age assemblages. The first of them includes *Fusulina complicata* Gryzlova, *F.* cf. *pakhrensis* Rauser, *F.* aff. *erecta* Zhao, Han et Wang, and *Putrella lui* Sheng of the late Moscovian age of the Middle Carboniferous. The second assemblage consists of *Schubertella* sp., *Triticites isfarensis* Bensh., *T. samarkensis* Sosnina, *T. subundulatus* Bensh., *T tianshanica* Bensh., and *T. variabilis* Rosovskaya. Most of these species characterize the uppermost Kasimovian Stage of the Fergana region and East European platform. It should be noted that the Middle and Late Carboniferous fusulinids were never registered in Inner Mongolia, and the provenance of corresponding pebbles remains unclear. The apparent thickness of this part of the section is several dozens of meters.

The overturned position of beds in the described section that has been formerly assumed is not confirmed, as it is incompatible with structural patterns of sandstone beds. Every subsequent bed has a sharp lower boundary and begins with coarse-grained sandstone grading upward into fine-grained variety and then into siltstone and, sometimes, in shale.

To the south of conglomerate exposures, there is a thick sequence of light gray, white, and greenish shales

of unknown age. Ding Yunjie *et al.* (1984) arbitrarily referred these rocks to the Upper Carboniferous. The contact between this sequence and conglomerates is probably tectonic.

Most important fossils discovered in the sandstone sequence are fusulinids and brachiopods. Fusulinids from limestone interbeds are represented by abundant tests of a new species of the *Monodiexodina* genus. This genus is widespread inside and beyond the Tethyan realm (Timan, Arctic Canada, western United States) in the Sakmarian to Midian deposits. Representatives of the genus are usually confined to sandy facies formed under relatively cold climatic condition (Han, 1980, Leven, 1983; Shi *et al.*, 1995). Such a wide stratigraphic range of the genus that includes poorly discriminated species is unfavorable for sediment dating. To assess the age of *Monodiexodina* Beds, one should use the accompanying fusulinid species, but unfortunately, no other fusulinids were found in the studied section. However, 300 km eastward of the study area, the *Monodiexodina* genus is accompanied by diverse *Parafusulina* forms and by representatives of genera *Yangchienia, Minojapanella*, "*Verbeekina*" (=Armenina), "*Misellina*" (=*Paramisellina*), *Pseudodoliolina*, "*Laxifusulina*" (*Dutkevitchia*), and others (Xia *et al.*, 1981, 1982). Assemblages of this kind are characteristic of the Kubergandian Stage in the Tethyan fusulinid scale (Leven, 1967, 1980) or of the Chisya Group middle part in the stratigraphic scheme of South China (Sheng and Jin, 1994).

Brachiopods occurring together with *Monodiexodina* forms in the Baotege 1 area are taxonomically uniform. They belong to the *Spiriferella–Kochiproductus–Yakovlevia* assemblage characteristic of the Zhesi Formation of the Honguer Ola area.

Northeast of the Baotege 1 area, there is exposed the fault-bounded sequence of varicolored shales of unknown age (Fig. 7). Farther to the northeast, it is replaced by a thick conglomerate sequence with coarse-grained sandstone interbeds (Fig. 7, section Baotege 2). Pebbles in conglomerates are subangular and largely composed of acid volcanics. Beds steeply dip northward. The thickness of the sequence is several hundreds of meters. To the west, it is truncated by a fault.

In the north, conglomerates are conformably overlain by massive thick-bedded biomicrites similar to those from the Lower Yihewusu Formation. Bryozoans and hydrozoans dominant among organic remains locally associate with accumulations of corals and brachiopods *Echinauris jisuensis* (Chao) and *Hemiptychina morrisi* Grabau. The limestone sequence is up to several hundreds meters thick, and its beds stretch southeastward over a distance of several kilometers forming a ridge well manifested in topography. Local conglomerate wedges are intercalated with limestones.

In the northeastern slope of the ridge, limestones conformably overlie conglomerates similar to those developed in the southwestern slope. Thus, limestones appear to be occurring in the core of a large synclinal fold, limbs of which are composed of sandy–conglomerate deposits (Fig. 7). In the northeast of the area under discussion, conglomerates are underlain by a thick sequence of acid volcanics, from which the majority of pebbles has been derived. Both in pebble composition and position in the section, conglomerates differ considerably from those of the Baotege 1 section described above.

Thus, the Baotege 2 section located north of the Baotege 1 locality shows the following rock succession (from the base upward):

(1) Acid volcanics at least 500–600 m thick; their contact with underlying strata is unexposed.

(2) Conglomerates about 1000 m thick with subordinate sandstone interbeds; pebbles in the rocks are mainly composed of underlying volcanics.

(3) Biohermal limestones up to 300–400 m thick and intercalated with conglomerates; the overlying rocks are unknown.

In this section, only limestones in the syncline core contain organic remains. Their coral assemblage is uniform and includes representatives of the genus *Diphycarinophyllum*, which are similar to forms occurring in the Lower Yihewusu Formation of the Honguer Ola section. The well-preserved bryozoans are represented by *Fistulipora* sp., *Dybowskiella* sp., *Anisotripella* sp., *Stenodiscus* sp., *Hinganella* sp., *Maychellina* sp., *Dyscritella* sp., *Ogbinopora* sp., and *Girtypora* sp. In its composition, this assemblage is identical to that from the Midian Chandalaz Formation of the Primor'e region. Brachiopods are typical of the *Streptorhynchus–Hemiptychina–Richthofenia* assemblage.

CORRELATION OF SECTIONS

Coming now to correlation of the studied sections, we should note the following:

(1) The considered sections of the Zhesi Honguer and Baotege areas are separated either geographically or stratigraphically. Different-type sections are confined to different tectonic blocks, and their peculiarities primarily reflect differences in synsedimentary development of blocks (different rates and magnitudes of subsidence, distance from provenance, and others). The considerable facies variability of Permian sequences in the study area should also be taken into consideration. Most of them can be referred to the marine molasses. The Zhesi and Lower Yihewusu formations that formed on the relatively raised and tectonically stable carbonate platform represent, presumably, an exception.

(2) Since the studied sections show significant lithological differences, their correlation is possible only with the help of paleontological criteria. They all bear similar faunal assemblages. This implies their partial or complete correspondence in age. The distinct well-traceable succession of carbonate strata in the Honguer

Ola Ridge, which yield most diverse fossil assemblages, can serve as a standard. The continuous rock succession of the Bulege Group cannot be reconstructed. It is possible to postulate only that this group as a whole corresponds in age to three formations of the Honguer Ola section (Fig. 8; Table).

As was mentioned, sandstones enclosing the limestone interbeds with *Monodiexodina* forms and referred to the Hugete Formation of the Baotege 1 section yield also brachiopods of the *Spiriferella–Kochiproductus–Yakovlevia* assemblage characteristic of the Zhesi Formation as well. Thus, the Hugete Formation corresponds, at least partly, to the Zhesi Formation. Limestones crowning the Baotege 2 section yield the brachiopod and coral assemblages similar to those from the Lower Yihewusu Formation. The possible correlation of these rocks is also evident from lithological similarity of limestones. As for the underlying conglomerate sequence, its upper part, at least, should be correlative with the Zhesi Formation according to position in the section. Acid volcanics underlying conglomerates can arbitrarily be referred to the Lower Permian (Fig. 8).

SOME BIOGEOGRAPHIC AND BIOSTRATIGRAPHIC INFERENCES

The Honguer Ola section is the unique, exhibiting in the continuous stratigraphic succession the replacement of faunal assemblages (mainly of brachiopod) characteristic of the temperate Boreal climatic zone by the typical thermophilic assembalges of the Tethyan type (brachiopods, corals, fusulinids).

In its taxonomic composition, the *Spiriferella–Kochiproductus–Yakovlevia* assemblage characteristic of the Zhesi Formation is of the boreal type. It is virtually identical to the Tsagan Ola brachiopod assemblage of Southern Mongolia. Consequently we may assume that shallow basins of Southern and Inner Mongolia were located during the Permian in the northern margin of Cathaysia at the boundary between the Boreal and Equatorial climatic zones (*Permskie bespozvonochnye...*, 1991).

In the Pechora region adjacent to the Urals, the *Spiriferella–Kochiproductus–Yakovlevia* assemblage corresponds to that from the Kozhimrudnitskaya Formation of the terrigenous section exposed along the Kozhim River. Most characteristic brachiopod genera of the latter are *Arctitreta, Yakovlevia, Thuleproductus, Kochiproductus, Cancrinella, Spiriferella, Kaninospirifer*, and others. The assemblage of the Pechora region is considered to be of the Late Permian (Ufimian) age, because it includes several genera missing from the Lower Permian strata, but widespread in Upper Permian deposits, including those of the Kazanian Stage stratotype, where their age is well substantiated. The thorough analysis indicates the early Ufimian (Solikamsk) age of host rocks. This is confirmed by data on distribution of other marine invertebrates (smaller foraminifers, bryozoans, bivalves) and by the results of palynological analysis (*Biota vostoka...*, 1998). The direct correlation between the Kozhimrudnitskaya Formation and Solikamsk Horizon of the Volga–Urals stratotype region is mainly based on distribution of smaller foraminifers and palynological assemblages. In western Arctic region, a similar brachiopod assemblage is characteristic of the lower part of the Kapp Starostin Formation of Spitsbergen (Kapp Starostin Formation, Woringen Member, *Sowerbina timanica* Zone; Nakamura *et al.*, 1987, 1992). The greater part of the Kapp Starostin Formation belongs to the Upper Permian, but the age of its lower part is still debatable. In the basal Kapp Starostin Formation, Polish researchers (Szaniawski and Malkowski, 1979) discovered conodonts *Neogondolella idahoensis* Younquist, Hawley et Miller, *N.* aff. *gracilis* Clark et Ethington, *Neostreptognathodus svalbardensis* Szaniawski, *Sweetocristatus arcticus* Szaniawski, *Xaniognathus* sp., and *?Ellisonia* sp. indicating the late Leonardian–early Roadian age of enclosing rocks (or the Kungurian–Ufimian age in terms of the East European scale).

Thus, beds of the Zhesi Formation in Inner Mongolia, which yield the *Spiriferella–Kochiproductus–Yakovlevia* brachiopod assemblage, can be correlated with the brachiopod-bearing beds of the Kozhimrudnitskaya Formation in the Pechora region and with basal beds of the Kapp Starostin Formation in Spitsbergen. Inasmuch as the latter are correlated with the basal Ufimian or uppermost Kungurian stages, the Zhesi Formation could also be considered as presumably corresponding to this age interval. As was mentioned however, brachiopods of this formation coexist with *Monodiexodina* forms, which associate with typical Kubergandian fusulinids in sections neighboring the study area. Accordingly, the Zhesi Formation is of the Kubergandian age in terms of the Tethyan scale. Such an assumption is consistent with data on corals whose assemblage has many species in common with that characterizing the Chisya Formation of South China. This is also confirmed by distribution patterns of brachiopods in the overlying Lower Yihewusu Formation, which indicate correspondence of their host strata to the Murgabian Stage of the Tethyan scale. The data obtained exclude a possibility that the basal Kapp Starostin Formation of Spitsbergen and Kozhimrudnitskaya Formation of the Pechora region belong the Kungurian Stage.

The considerable similarity between marine faunas of Inner and Southern Mongolia, on the one hand, and western Arctic region, on the other, could be partly controlled by similar climatic conditions that existed in these areas geographically remote from each other (*Permskie bespozvonochnye...*, 1991). The similarity of their brachiopod assemblages at the generic and, frequently, species levels suggests the short-term migratory links between West Arctic and Cathaysian basins. It can be assumed that the migratory pass to the Paleotethys existed along the eastern slope of the Urals

Upper Permian formations of the Zhesi Honguer section correlated with stages of the East European and Tethyan scales

Cis-Urals, East European platform			Inner Mongolia					Tethys	Proposed International scale	
			sections		faunal assemblages					
Series	Stage	Horizon	Honguer Ola	Bulege	fusulinids	brachiopods	corals	Stage	Series	Stage
Upper	Tatarian	Vyatka	?	?				Dorashamian	Lopingian	Changhsingian
								Dzhulfian		Wuchiapingian ?
		Severnaya Dvina	Upper Yihewusu Fm.		*Pseudofusulina solita- P. trivialis- P. kwangchiensis*	*Haydenella kiangsiensis*	*Waagenophyllum indicum*	Midian	Guadalupian	Capitanian ?
		Urzhum	Lower Yihewusu Fm.	Bulege Group	*Codonofusiella– Sichotenella– Pseudofusulina kwangchiensis*	*Streptorhynchus– Hemiptychina– Richthofenia*	*Waagenophyllum– Wentzelella*	Murgabian		Wordian ?
	Kazanian	Povolzhskii								
		Sok					*Paraduplophyllum multiplicatum– Lopholasma bellum*			
	Ufimian	Sheshma	Zhesi Fm.			*Spiriferella– Kochiproductus– Yakovlevia*		Kubergandian		Roadian ?
		Solikamsk			*Monodiexodina*		*Tachylasma zhesiense–Callo- phyllum sinense*			
Lower	Kungurian	Iren	?	?				Bolorian	Cisuralian	Kungurian
		Filippovosk								

(where data on distribution of the mid-Permian marine facies are limited) and southwestern margin of the Siberian platform (Grunt, 1994). Such an assumption is consistent with palinspastic reconstructions for the Permian time (Scotese and McKerrow, 1994).

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REFERENCES

Biota vostoka Evropeiskoi Rossii na rubezhe rannei i pozdnei permi, Grunt, T.A., Esaulova, N.K., and Kanev, G.P., Eds., (Biota of the East European Russia across the Early–Late Permian Boundary), Moscow: GEOS, 1998.

Ding Yunjie, Xia Guoying, Duan Chenghua, *et al.*, Study on the Early Permian Stratigraphy and Fauna in Zhesi District, Nei Mongol Zizhiqu (Inner Mongolia), *Bull. Tianjin Inst. Geol. Min. Res.*, 1984, no. 10.

Grabau, A.W., The Permian of Mongolia, *Am. Museum Natur. History*, 1931, vol. 4.

Grunt, T.A., Standard Permian Biostratigraphic Scale with Respect to Permian Biogeography, *Permophiles*, 1994, no. 26, pp. 21–25.

Han, J.X., The Morphology, Evolution and Distribution of the Genus Monodiexodina and Its Allied Genera, *Bull. Shengyang Inst. Geol. Miner. Res.*, 1980, no. 1, pp. 90–102.

Leven, E.Ja., Early Permian Fusulinids from the Central Pamir, *Riv. It. Paleont. Strat.*, 1993, vol. 99, no. 2, pp. 151–198.

Leven, E.Ya., *Ob"yasnitel'naya zapiska k stratigraficheskoi shkale permskikh otlozhenii oblasti Tetis* (Explanatory Note to the Permian Stratigraphic Scale for the Tethyan Region), Leningrad: Vses. Geol. Inst., 1980.

Leven, E.Ya., *Stratigrafiya i fuzulinidy permskikh otlozhenii Pamira* (Stratigraphy and Fusulinids from Permian Deposits in the Pamirs), Moscow: Nauka, 1967.

Li Liang-Fang, On Study of Lower Permian of Zhesi Hongor in Demao County of Inner Mongolia, *J. Changchun Geol. Inst.*, 1980, no. 3, pp. 21–32.

Manankov, I.N., Reference Section and Upper Permian Zonation in Southeastern Mongolia, *Stratigr. Geol. Korrelyatsiya*, 1999, vol. 7, no. 1, pp. 56–65.

Nakamura, K., Kimura, G., and Winsnes, Th., Brachiopod Zonation and Age of the Permian Kapp Starostin Formation (Central Spitsbergen), *Polar Research. N.S.*, 1987, no. 5, pp. 207–219.

Nakamura, K., Tazawa, J., and Kumon, F., Permian Brachiopods of the Kapp Starostin Formation, *Investigations of the Upper Carboniferous–Upper Permian Succession of Western Spitsbergen, 1989–1991*, Sapporo: Hokkaido Univ, 1992, pp. 77–95.

Permskie bespozvonochnye Yuzhnoi Mongolii. Tr. Sovetsko-mongol'skoi paleontologicheskoi ekspeditsii (Permian Invertebrates of Southern Mongolia), Moscow: Nauka, 1991, issue 40.

Scotese, Ch.R., and McKerrow, Revised World Maps and Introduction, *Palaeozoic Palaeogeography and Biogeography. Mem. Geol. Soc. London*, 1994, no. 12.

Sheng Jin-Zhang, Jin Yu-Gan, Correlation of Permian Deposits in China, *Palaeoworld, No 4. Permian Stratigraphy, Environments and Resources, vol. 1: Palaeontology & Stratigraphy*, Nanjing: Univ. Press, 1994, pp. 14–114.

Shi, G.R. and Archbold, N.W., and Zhan, L.P., Distribution and Characteristics of Mixed (transitional) Mid-Permian (Late Artinskian–Ufimian) Marine Faunas in Asia and Their Palaeogeographical Implications, *Palaeogeogr., Palaeoclimatol., Palaeoecol.*, 1995, vol. 114, pp. 241–171.

Skinner, J.W., Permian Foraminifera from Turkey, *Univ. Kansas Paleont. Contr.*, 1969, Paper 36, pp. 1–14.

Szaniawski, H. and Malkowski, K., Conodont from Kapp Starostin Formation (Permian) of Spitzbergen, *Acta Paleontol. Polonica*, 1979, vol. 24, no. 2, pp. 231–264.

Xia Guoying, Early Permian Fusulinids from Maolipenhong Region in Nei Mongol Zizhiqu, *Bull. Tianjin Institute Geol. Mineral. Res.*, 1982, no. 5, pp. 133–147.

Xia Guoying, Zonation of the Early Permian Fusulinid-Bearing Strata in Inner Mongolia, *12th Annual Conference of the Palaeontological Society of China, Selected Papers*, 1981, pp. 116–126.

Stratigraphy and Geological Correlation, Vol. 9, No. 5, 2001, pp. 454–472. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 9, No. 5, 2001, pp. 40–58.
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Event Stratigraphy and Correlation of Kazanian Marine Deposits in the Stratotype Area

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Abstract—In the history of the Kazanian sea basin in the Russian plate, periods of quasi-stationary shoreline position alternated with quick phases of transgressions and regressions. The last events were responsible for appearance of facies boundaries in the Kazanian Stage sections. These "transgression–regression" boundaries are most distinct in sections of supratidal zone deposits of diverse facies composition. Boundaries of that kind are isochronous and enable the detailed correlation of marine deposits in remote sections. In this work, the lower Kazanian deposits of the Toima–Izh interfluve (lower courses of the Kama River) are correlated with their stratotype at the Sok River (Samara region). Gray deposits of the interfluve area are attributed to the Baitugan Beds separating two red-bed sequences, namely the underlying deposits of the Ufimian Stage and overlying Kamyshlov Beds. Both units of red beds are of continental origin, whereas the Baitugan Beds include the sea-bar, lagoonal, and deltaic facies tracts.

Key words: Russian plate, Kama River lower courses, Kazanian Stage, supratidal deposits, facies, transgression, regression, cyclostratigraphy, correlation.

The detailed regional stratigraphic scheme of Kazanian Stage for the Russian plate cannot be created without correlation of corresponding individual sections. The huge epicontinental Kazanian sea was of decreased salinity and had limited connections with the ocean located "to the north"[1] Faunas of that sea consisted of euryhaline forms insignificantly changeable with time and characterizing now particular rock facies, diversity of which is a distinctive feature of the Kazanian Stage. Such a situation restricts applicability of the traditional biostratigraphic method. The experience with the Kazanian Stage subdivision in the Middle Volga and Lower Kama regions, where the detailed stratigraphic schemes have been already elaborated, shows that palynological study and investigation of cyclic sedimentary units are more advantageous in this case than other stratigraphic approaches.

The well-known cyclostratigraphic scheme of wide usage in geological practice is that originally suggested by Forsh (1951, 1955) and recurrently revised in subsequent periods (Tikhvinskaya, 1967; Ignat'ev *et al.*, 1970; Ignat'ev, 1977; Solodukho and Tikhvinslaya, 1977). In the last version of the scheme (*Resheniya...*, 1990), Kazanian deposits are divided into eight cyclic units of the first rank (four in each substage), which are authorized as the Bugul'ma, Baitugan, Kamyshlov, Barbashino, Prikazanskaya, Pechishchi, Verkhnii Uslon, and Morkvashino sequences. In view of imperfect procedure used to recognize and correlate cyclic units, the above subdivisions are actually not identical in rank and inappropriate for remote correlations, which can be performed only by continuous tracing of particular beds through a series of closely spaced sections. When correlating end sections of a long profile via intermediate localities, one obtains a considerable cumulative error so that many sections (even the substage stratotypes) can be mistakenly correlated.

The palynological stratigraphic scheme was suggested by Bogov (1971) who distinguished eight complexes of palynomorphs, four in each of two Kazanian substages. Unfortunately, his scheme was published in a generalized form without indication of palynological assemblages from concrete localities. He described them as characteristic of eight units of the cyclostratigraphic scheme that was erroneous in some points, as is mentioned above. As a result, some assemblages had happened to be not of those cyclic units, to which Bogov attributed them, and his scheme is hardly suitable for further detailing. The general palynostratigraphy of the Kazanian Stage has been revised recently by Bludorova and Bogov (1996), who distinguished 19 palynomorph assemblages this time, and also by Shelekhova (1996) who described 14 assemblages.

All above schemes are of local significance, but they provide some grounds for regional correlation and can be useful by creation of regional stratigraphic scheme of the Kazanian Stage. The best way to attain the last objective is to study supratidal deposits of the Kazanian Stage. Precisely these deposits recorded the most com-

[1] The current disposition of four corners of the Earth is used here and further on. As it may be different from that of the Kazanian time, apt geographic indications are placed in inverted commas.

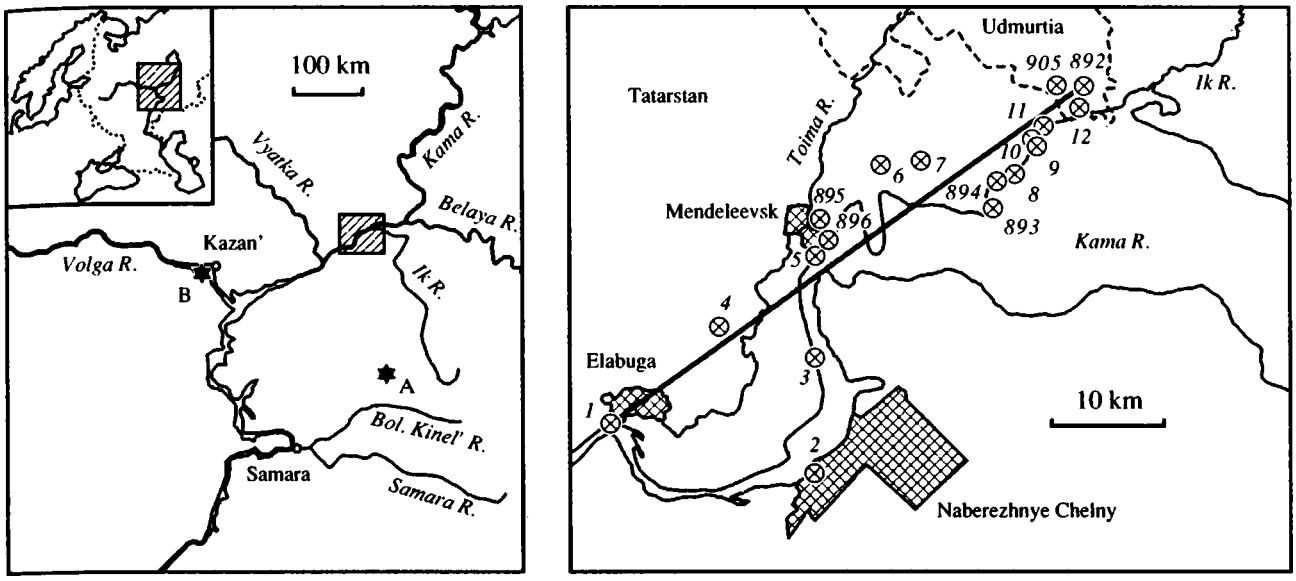

Fig. 1. Location maps showing stratotype areas of lower (A) and upper (B) Kazanian substages, and disposition of sections discussed in this work: (*1*) Elabuga; (*2*) Naberezhnye Chelny; (*3*) Bogatyi Dol Ravine; (*4*) Klyuchevka site; (*5*) Tikhie Gory Wharf; (*6*) Setyakovo village; (*7*) Bezyaki village; (*8*) right bank of the Kama River, 1.3 km upstream off the Chuman River mouth; (*9, 10*) Izhevka village; (*11*) Rudnyi Log Ravine; (*12*) Borehole 4, Golyusherminka River; (*892*) Golyusherma section; (*893*) Ikskoe Ust'e site; (*894*) Turaevo section; (*895*) Bondyuga section; (*896*) Tikhie Gory site; (*905*) Golyusherminka River site.

plete history of the Kazanian sea. In addition, they are rich in facies favorable for accumulation of microphytofossils.

MATERIALS

Numerous outcrops in the Kama River lower riches characterize the complete succession of the Kazanian coastal-marine deposits and sedimentary strata underlying and overlying them. They are situated between the stratotype areas of the lower and upper Kazanian substages (Fig. 1). The lowermost Kazanian beds of coastal-marine origin are exposed on both sides of the Kama River upstream off the town of Elabuga, between the Toima and Izh river mouths. In 1989, 1990 and 1998, I studied these beds in the following six localities (Fig. 1): Site 892, the Pervye Prudki Ravine near the Blagodat' Village (Golyusherma); Site 893, the right side of the Kama River near the Ikskoe Ust'e Village; Site 894, quarry near the Turaevo Village, right side of the Kama River; Site 896, northern outskirts of Mendeleevsk, right side of the Kama River; Site 895, quarry near the Bondyuga Village situated northeastward of Mendeleevsk; and Site 905, a nameless ravine on the left side of the Golyusherminka River, 1 km westward of the Blagodat' Village. Rocks of the Golyusherma, Turaevo, and Bondyuga sections were sampled for palynological analysis (Fig. 2). These key sections are described below.

Plotting the facies profile, I also used the published description of sections studied in the following localities (Figs. 1, 5): (*1*) Kama River right side near Elabuga (Egorov, 1932; Chernomorski, 1932; Silant'ev *et al.*, 1998); (*2*) Kama River left side near the Naberezhnye Chelny (Zaitsev, 1878); (*3*) Bogatyi Dol Ravine, the right side of that river 9 km downstream off the Tikhie Gory wharf (Egorov, 1932); (*4*) Klyuchevka Ravincavine at the left side of the Korinka River (Egorov, 1932); (*5*) right side of the Kama River 1.5 km downstream off the Tikhie Gory wharf (Egorov, 1932); (*6*) nameless ravine near Setyakovo (Egorov, 1932); (*7*) Bezyak Creek 3 km upstream off the Bezyaki Village (Egorov, 1932); (*8*) right side of the Kama River 1.3 km upstream off the Chuman River mouth (Egorov, 1932); (*9, 10*) Izhovka Village (Zaitsev, 1878; Noinskii, 1924); (*11*) head area of the Rudnyi Log Ravine 1 km northward off the Izhovka Village (Bludorov, 1938); Borehole 4 near the Golyusherminka River mouth (Bludorov, 1938).

Golyusherma Section (Site 892)

Udmurtia, Alnash district, Blagodat' Village, Pervye Prudki Ravine, the left branch of the Takhtashur (Shakhterskii) Ravine at the right side of the Golyusherminka River, the right tributary of the Izh River (Fig. 1): the site is known as the Golyusherma locality of Permian tetrapods (Efremov and V'yushkov, 1955; Golubev, 1992), but the toponym is now spelled as Golyushurma, and I use here both names in their proper meaning.

Opposite the Blagodat' village, the following bed succession has been distinguished in the thalweg of the Pervye Prudki Ravine about 50 m upstream of its mouth (Figs. 2, 3):

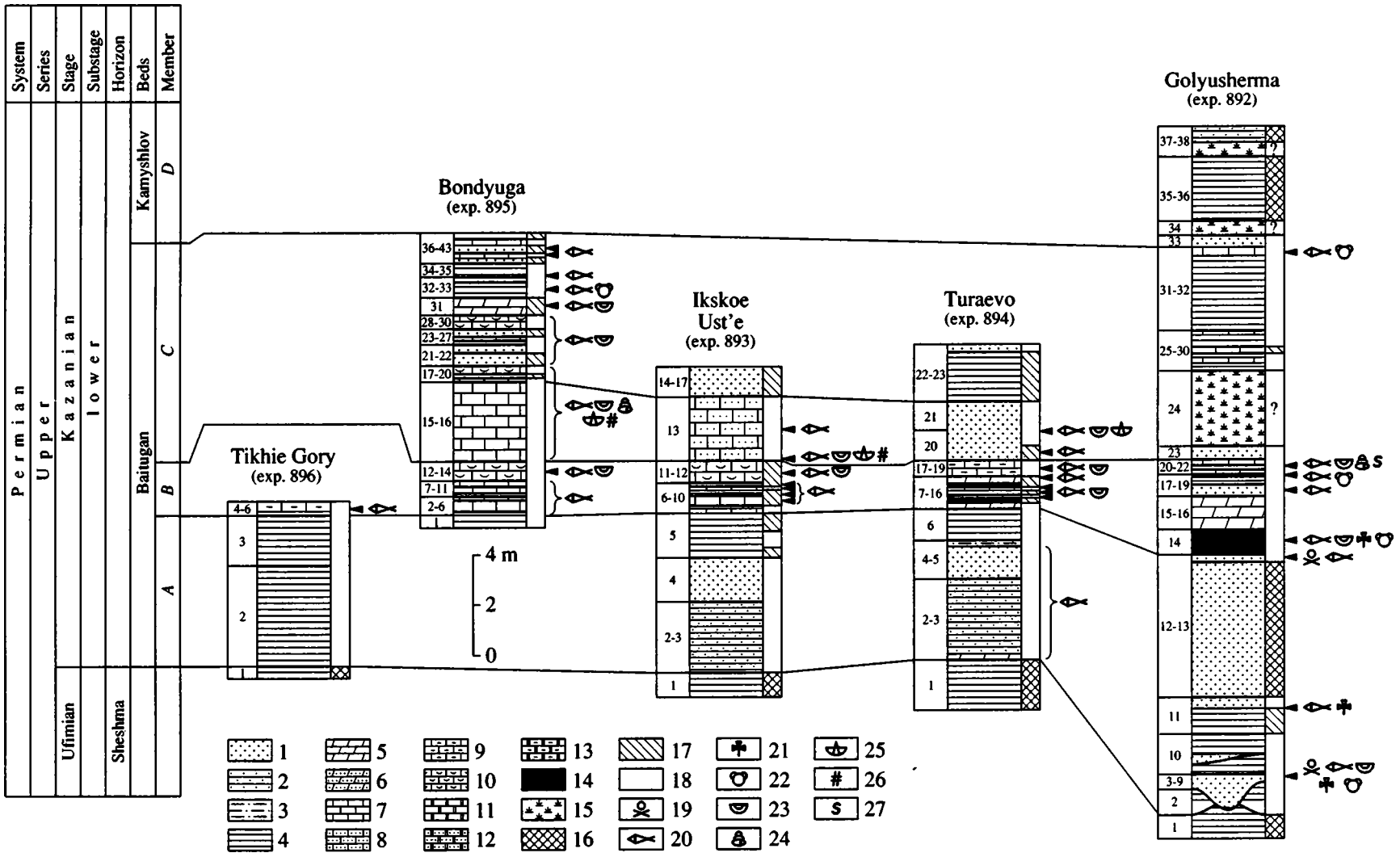

Fig. 2. Correlated sections of Upper Permian deposits in the Toima–Izh interfluve area: (1) sandstone; (2) alternating clay, siltstone, and sandstone beds; (3) siltstone; (4) clay; (5) marl; (6) sandy marl; (7) limestone; (8) sandy limestone; (9) clayey limestone; (10) limestone with abundant invertebrate shells; (11) dolomite; (12) sandy dolomite; (13) clayey dolomite; (14) coal; (15) talus; (16) red beds; (17) yellow to brown beds; (18) gray beds; (19) bones of terrestrial vertebrates; (20) fish remains; (21) macrophytofossils; (22) microphytofossils; (23) bivalves; (24) gastropods; (25) brachiopods; (26) bryozoans; (27) serpulids (figures on right indicate bed nos.).

Ufimian Stage

(1) Vinous clay; rock is massive, bearing abundant nodules of brown marl and detritus of carbonized wood. Apparent thickness is 1.5 m.

Kazanian Stage, Baitugan Beds, Member "A"

(2) Yellow to grayish green clay; rock is horizontally bedded, bearing green marly nodules (up to 5 cm across). Its boundary with Bed 1 is sharp, uneven, having pocket-like concavities. The bed is 1.5 m thick.

(3) Lilac-gray sandstone; rock is fine-grained, massive, corresponding to rhisosphere in the upper part of the bed, where carbonized root remains are concentrated (Fig. 4). The bed yields microphytofossils of the *Vittatina vittifera* f. *minor–V. subsaccata* palynological assemblage (PA II after Shelekhova and Golubev, 1993a, 1993b; PA I after Shelekhova, 1996). This lenticular bed is over 2 m long and up to 0.6 m thick.

(4) Gray clay; rock is massive, rich in carbonized plant detritus. The lentil is more than 4 m long and up to 0.25 m thick.

(5) Brown clay with grayish or yellowish tint; clay is fine-laminated, silty, enclosing remains of fish scale. The lower boundary of the bed is uneven, showing deep (10 cm) pocket-like concavities. The bed yields microphytofossils of the *Cyclogranisporites polypyrenus–Lycospora* palynological assemblage (PA III after Shelekhova and Golubev, 1993a, 1993b; PA II after Shelekhova, 1996). The lentil is over 0.5 m long and up to 0.15 m thick.

(6) Gray sand, medium-grained and cross-bedded, bearing abundant carbonized detritus; the bed is lenticular, over 4 m long and up to 0.2 m thick.

(7) Gray sandstone; rock is medium-grained, massive, enclosing intraformational pebbles and gravel (light gray, highly calcareous clay), and yielding shells of *Palaeomutela* sp. Abundant fish scale is that of *Acentrophorus varians* (Kirkby), *Elonichthys contortus* Esin, *Kasanichthys golyushermensis* Esin, *Palaeostrugia rhombifera* (Eichwald), *Watsonichthys* sp., *Grygorichthys* sp., *Palaeoniscum kasanense* Geinitz et Vetter, *Acrolepis* cf. *sedgwicki* Agassis, *Acropholis kamensis* Esin, *Acr. stensioei* Aldinger, *Amblypterina* sp., *Paramblypterus* sp., *Boreolepis jenseni* Aldinger, *Plegmolepis* sp., *?Pygopterus* sp., *Platysomus* cf. *striatus* Agassis, *Koinichthys ivachenkoi* Esin, *Eurysomus* sp., *?Kargalichthys* sp., and *Wardichthys inobilis* Esin. Associated fossils are tooth remains of Hybodontoidea sharks (fam. indet.) and bones of tetrapods *Melosaurus compliatus* Golubev, *Microsyodon orlovi* Ivachnenko, Leptorophidae gen. indet., and *Platyoposaurus* sp.[2] The bed also yields microphytofossils of the *Striatohaploppinites perfectus–Limitisporites* palynological assemblage (PA IV after Shelekhova and Golubev, 1993a, 1993b; PA III after Shelekhova, 1996). The bed of lenticular shape is over 1.6 m long and up to 0.1 m thick.

(8) Gray sandstone; rock is medium-grained, locally carbonized and bearing bivalve shells, fish scale, and carbonized plant remains. *Cordiacarpus* sp. and some other forms were identified among the latter. The bed is 0.05–0.3 m thick.

(9) Gray fine-grained cross-bedded sand; the bed is 0.05–0.2 m thick.

(10) Dark gray clay; clay is horizontally laminated, enclosing carbonized plant detritus and sandstone lentils or interbeds (up to 0.5 m) in the lower part of the bed. Sandstone with carbonized detritus is gray, fine-grained, showing fine lamination. The bed is 1.6 m thick.

(11) Brown clay grading upward into intercalated lentils of gray marl and sandstone; clay is horizontally laminated, sandy, bearing abundant small-sized detritus of carbonized plant remains. The upper part of the bed yields fish scale and abundant plant fossils: *Compsopteris* sp. (aff. *adzvensis* Zal.), *Cordaites* vel *Rufloria* sp., *Cordiacarpus* sp., *Cordiacarpus* cf. *chalmerjanus* Dombr., *Lepidophyta* indet. (preservation type *Aspidiaria*), *Nucicarpus* sp., "*Odontopteris*" *rossica* Zal., *Paracalamites* aff. *striatus* (Schmalhausen), and *Pecopteris* sp., cf. *Prynadaeopteris* (?) *minuta* Vlad. The lover boundary of the bed is uneven, with pocket-like concavities. The bed is 1.5 m thick.

(12) Rust-brown sandstone; rock is massive to cross-bedded. The bed is 5–6 m thick.

(13) Greenish gray sandstone; rock is fine-grained, with marcasite cement. Intercalated lentils with gray marl gravel yield tetrapods and fish remains. The bed is 0.5 m thick.

Member "B"

(14) Coal seam with intercalations of dark gray clay coaliferous to a variable extent; abundance of clay admixture decreases upward. In addition to bivalves, the bed yielded remains of fishes *Palaeoniscum kasanense* Geinitz et Vetter, *Kasanichthys golyushermensis* Esin, *Acropholis kamensis* Esin, and plant fossils *Paracalamites* sp. Microphytofossils from the bed represent the *Striatohaplopinites perfectus–Limitisporites* palynological assemblage (PA IV after Shelekhova and Golubev, 1993a, 1993b; PA III after Shelekhova, 1996). The seam is 1.0 m thick.

(15) Yellowish gray marl; rock is fine-laminated to foliated. The bed is 0.9–1.0 m thick.

(16) Bluish gray massive and dense bituminous marl; the bed is 0.3 m thick.

(17) Yellowish gray sandstone; rock is fine-grained, yielding scarce scale of fishes *Acentrophorus* sp., *Palaeoniscum kasanense* Geinitz et Vetter, *Kasanich-*

[2] Throughout the paper, *Palaeoniscum* species are cited from works by Esin (Esin, 1995; Esin and Mashin, 1996); plant remains are identified by S.V. Naugol'nykh (GIN RAS), and bivalves by V.V. Silant'ev (MSU).

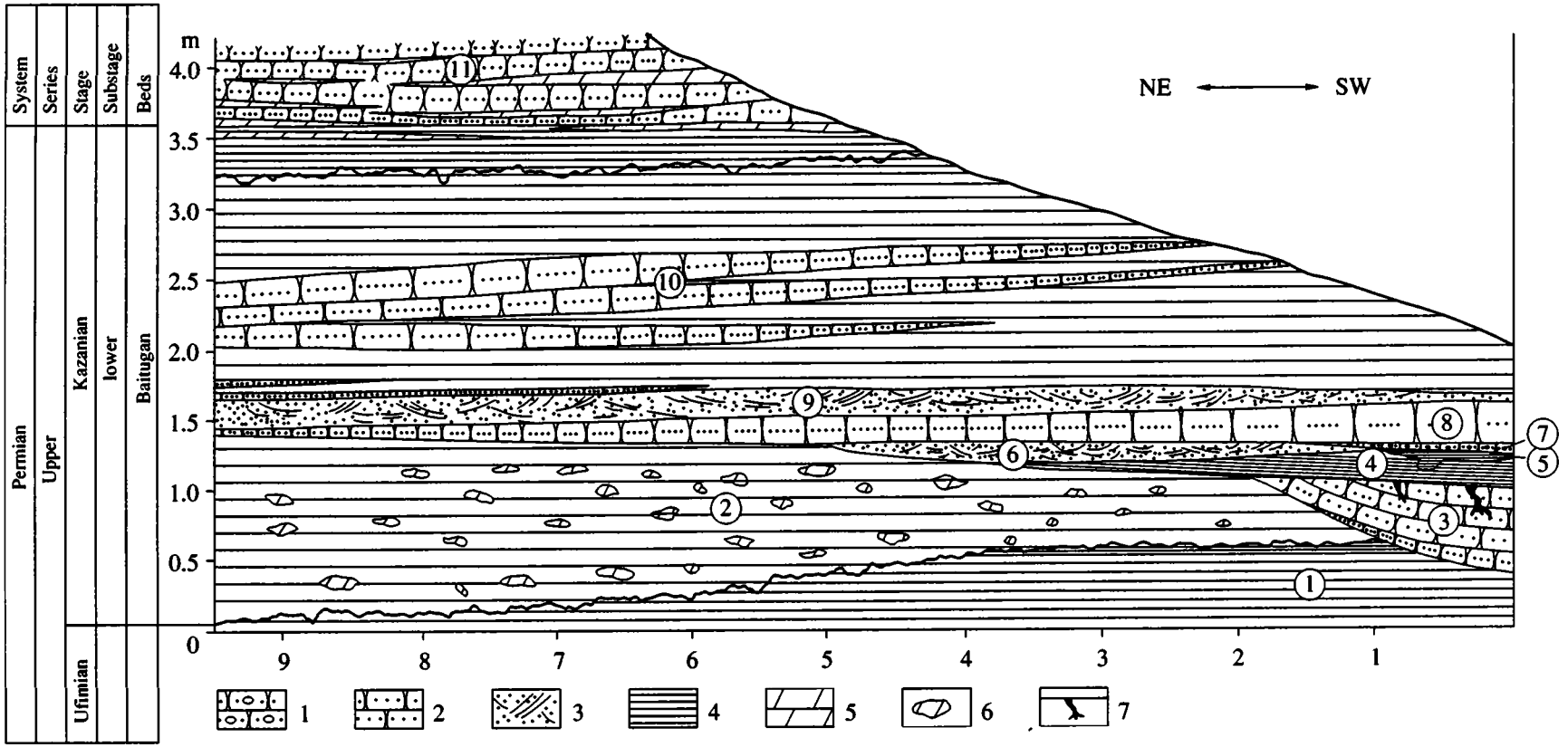

Fig. 3. Lower Baitugan Beds of the Kazanian Stage, Golyusherma section: (1) sandstone with marl gravel; (2) sandstone; (3) cross-bedded sand; (4) clay; (5) marl; (6) marl nodules; (7) carbonized plant roots (bed numbers are encircled).

thys golyushermensis Esin, and *Acropholis kamensis* Esin. The bed is 0.5 m thick.

(18) Dark gray clay; the bed is 0.3 m thick.

(19) Clayey slaty coal yielding plant fossils and fish scale of *Acropholis kamensis* Esin, *Acr. stensioei* Aldinger, and *Palaeoniscum kasanense* Geinitz et Vetter; microphytofossils of the *Striatohaplopinites perfectus–Limitisporites* assemblage (PA IV after Shelekhova and Golubev, 1993a, 1993b; PA III after Shelekhova, 1996) are detected as well. The seam is 0.1 m thick.

(20–22) Dark gray massive limestone beds with intercalations of gray clay; rocks yield polychaetes *Spirorbis* cf. *permianus* King, gastropods *Goniasma* sp., *G.* (?) *biarmica* (Kutorga), *Naticopsis* sp., and bivalves *Pseudomonotis garforthensis* King, *Ps. speluncaria* (Schloth.) in association with fish remains *Acentrophorus* sp., *Palaeoniscum kasanense* Geinitz et Vetter, *Kasanichthys golyushermensis* Esin, *Acropholis kamensis* Esin, *Platysomus* sp., and *Acrolepis* sp. The beds are 0.6 m thick in total.

Member "C"

(23) Yellowish gray sandstone; rock is fine-grained, cross-laminated and weakly cemented. The apparent thickness of the bed is 0.5 m.

(24) Talus; the unexposed interval is about 3 m.

(25) Brownish gray clay with intercalations of brownish gray massive and hard limestone; the bed is 0.25 m thick.

(26) Mottled, dark gray to light brown limestone; rock is massive, dense and hard. At the base, it is gray-yellow and sandy, resting on fine-laminated fragile marl. The bed is 0.25 m thick.

(27) Gray, slightly bluish, dense and lumpy clay; rock is intercalated with interlayer (4 cm) of yellowish gray flaggy marl. The bed is 0.15 m thick.

(28) Gary-brown massive hard limestone; scarce carbonized detritus is dispersed in rock. The bed is 0.25 m thick.

(29) Clay as in Bed 27; the bed is 0.5 m thick.

(30) Mottled, pinkish gray to cream-gray limestone; rock is very hard, vaguely bedded and very clayey, approaching marl in composition; carbonized plant detritus is scarce. The bed is 0.1–0.15 m thick.

(31) Gray, slightly bluish clay; rock is dense and lumpy, intercalated with marl and yellow clay interlayers. Near the top, there is a coaly interlayer (7 cm), above which the clay is gray-yellow. The bed is 3.0 m thick.

(32) Gray massive limestone with carbonized plant detritus and thin interlayers of gray clay; the bed yields abundant fish scale of *Acentrophorus varians* (Kirkby), *Palaeostrugia rhombifera* (Eichwald), *Acrolepis* cf. *sedgwicki* Agassis, *Acropholis* sp., *Kasanichthys golyushermensis* Esin, *Palaeoniscum kasanense* Geinitz et Vetter, *Platysomus* cf. *striatus* Agassis, and *Watsonichthys* sp. Microphytofossils from the bed are typical of the *Striatohaplopinites perfectus–Schizosporis permianus* palynological assemblage (PA V after Shelekhova and Golubev, 1993a, 1993b; PA IV after Shelekhova, 1996). The bed is 0.35 m thick.

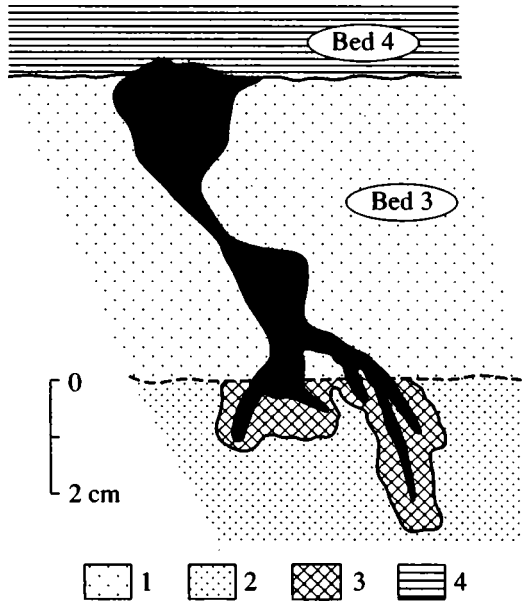

Fig. 4. Carbonized plant root in deltaic deposits of the Golyusherma section, lower part of Member A in the Baitugan beds of the lower Kazanian Substage: (1) dark gray sandstone; (2) gray-lilac sandstone; (3) ferruginate sandstone; (4) gray clay.

Kamyshlov Beds, Member "D"

(33) Yellowish green polymictic sandstone that is poorly lithified; the bed is 0.5 m thick.

(34) Talus; the unexposed interval is 0.5 m.

(35–38) Alternating beds of brown clay and sandstone; the apparent thickness is 3.8 m.

Turaevo Section (Site 894)

Tatarstan, Mendeleevsk district, Turaevo village; the quarry with rock exposures is located 1 km to the south of the village at the right side of the Kama River slightly above the Chuman River mouth (Fig. 1). The section is described from the base upward (Fig. 2).

Ufimian Stage

(1) Brown silty clay; the apparent thickness is 2.0 m.

Kazanian Stage, Baitugan Beds, Member "A"

(2) Gray to yellowish brown silty marl with abundant carbonized or ferruginate plant remains; large though rare fish scales are dispersed in rock. The coaly

interlayer near the top exhibits malachite and azurite incrustations. The bed is 0.25 m thick.

(3–5) Alternating lenticular beds of sandstone, siltstone, clay, and marl; gray to brown-gray fine-grained sandstone varieties are usually massive or horizontally bedded, bearing sporadic flattened pebbles (up to 3 cm long) of yellowish gray marl. Flaggy or foliated sandstone interbeds are less frequent. Sandstone beds yield carbonized or ferruginate plant detritus and small invertebrate shells. Beds of gray silty clay and marl yield scarce fish scales and carbonized plant remains. The total thickness is 4.40–4.65 m.

(6) Yellowish to greenish gray silty clay; the bed with vertical fucoids is 1.25–1,3 m thick.

Member "B"

(7) Dark gray clay; the bed is 0.05–0.07 m thick.

(8) Dark gray massive bituminous limestone; branching ferruginate "channels" pierce the bed in various directions. Carbonized plant remains show oblique or vertical orientation. The bed is 0.2 m thick.

(9) Variegated, gray, yellow, brown or black clay with coaly interlayers in the middle and near the top; rocks are horizontally bedded. The bed is 0.2 m thick.

(10) Gray fine-laminated bituminous limestone; the bed yields carbonized plant remains, bivalve casts, and fish scale. Its thickness is 0.15 m.

(11) Dark brown clay with horizontal bedding; fish scale, bivalve casts, and plant detritus are abundant. The bed is 0.1 m thick.

(12, 13) Clay and marl intercalated with brown-gray bituminous limestone; rocks showing horizontal bedding yield fish scale and carbonized plant remains. The total thickness is 0.25–0.3 m.

(14) Black coaly clay locally grading into coal; the seam is 0.05–0.08 m thick.

(15) Dark brown detrital limestone with carbonized plant detritus; the bed is 0.2 m thick.

(16) Brown clay yielding fish scales; the bed is 0.05 m thick.

(17–19) Brown-gray organogenic-detrital limestone beds with intercalations of gray and brown foliated silty marls; rocks yield bivalve shells, fish scale, and plant detritus; their total thickness is 0.68 m.

Member "C"

(20) Brown to gray sandstone; rock is fine- to medium-grained, clayey, vaguely laminated, enclosing coaly seams. Remains of bivalves, brachiopods, fishes, and plants are abundant. The bed is 1.1–1.3 m thick.

(21) Brown-gray fine-grained sandstone; rock is massive or thick-bedded, bearing plant remains. The bed is 1.0–1.1 m thick.

(22) Dark gray-brown silty clay showing horizontal bedding and yielding plant remains; the bed is 2.0 m thick.

(23) Gray fine-grained flaggy sandstone; vague lamination and broad ripple marks are characteristic of this bed that is 0.3 m thick.

Bondyuga Section (Site 895)

Tatarstan, Mendeleevsk district, Bondyuga Village (northeastern outskirts of the town); section is exposed in southeastern wall of the quarry adjacent to the village on the north (Fig. 1). The following bed succession is distinguished here beginning from the wall base and working up (Fig. 2).

Kazanian Stage, Baitugan Beds, Member "A"

(1) Gray-green bog clay; the apparent thickness is 0.5 m.

Member "B"

(2) Dark gray clay bed that is 0.15 m thick.

(3) Dark gray bituminous limestone; rock is very dense, horizontally laminated, pierced by a network of thin branching "channels." Fish remains *Acentrophorus varians* (Kirkby), *Elonichthys contortus* Esin, *Kasanichthys golyushermensis* Esin, *Acropholis kamensis* Esin, *Acr. stensioei* Aldinger, *Platysomus* cf. *striatus* Agassis, *Eurysomus* sp., and *Palaeoniscum kasanense* Geinitz et Vetter are identified in the bed that is 0.18 m thick.

(4–11) Gray limestones intercalated with gray clay interbeds and coal seams; rocks are horizontally bedded to foliated, yielding fish remains *Acentrophorus varians* (Kirkby), *Palaeoniscum kasanense* Geinitz et Vetter, *Watsonichthys* sp., *Kasanichthys golyushermensis* Esin, *Amblypterina* sp., *Elonichthys* sp., and *Platysomus striatus* Agassis in association with plant remains. Beds are 1.07 m thick in total.

(12–14) Gray dense limestones enclosing an interlayer of yellow silty clay; rocks yield abundant bivalve shells and fish scale of *Elonichthys contortus* Esin, *Platysomus striatus* Agassis, and *Amblypterina* sp. Beds are 0.75 m thick in total.

Member "C"

(15–16) Light gray massive detrital limestones; rocks are cavernous, showing fucoids and yielding brachiopod, gastropod, bivalve, bryozoan, and fish remains. *Palaeoniscum kasanense* Geinitz et Vetter, *Acentrophorus varians* (Kirkby), *Kasanichthys golyushermensis* Esin, *Watsonichthys* sp., *Elonichthys* sp., *Amblypterina* sp., and *Platysomus striatus* Agassis are identified among the latter. Beds are 3.15 m thick in total.

(17–20) Brown-gray bituminous limestones with brown clay interlayers; rock yield brachiopod, bivalve,

bryozoan, fish, and carbonized plant remains. Beds are 0.65 m thick.

(21–27) Brown sandstones; rock is fine-grained, flaggy, weakly lithified, with carbonized plant detritus and fish remains *Acentrophorus varians* (Kirkby), *Elonichthys contortus* Esin, and *Palaeonisum kasanense* Geinitz et Vetter, with gray marl and limestone interbeds; carbonate rocks contain abundant cavities left by dissolved bivalve shells. The total thickness is 1.5 m.

(28–30) Brown-gray limestones; rocks bear fish scale and are cavernous because of dissolution of bivalve shells. Beds are 0.55 m thick.

(31) Brown-black marl with horizontal bedding; rock yields small (2–3 cm) bivalve shells, fish scale, and plant remains, mostly their carbonized detritus. The bed is 0.70–0.75 m thick.

(32, 33) Gray fine-laminated clay with a coal seam in the upper bed; rocks yield fish scale and ferruginate plant remains. Their total thickness is 0.8 m.

(34) Gray marl; rock is fine-laminated to foliate, yielding fish scale of *Palaeoniscum kasanense* Geinitz et Vetter, *P. freiselebeni* Blainville, *Acentrophorus varians* (Kirkby), *Elonichthys contortus* Esin, *Watsonichthys* sp., *Platysomus striatus* Agassis, *Boreolepis jenseni* Aldinger, *Kasanichthys golyushermensis* Esin, *Acropholis kamensis* Esin, *Acr. stensioei* Aldinger, and plant detritus. Microphytofossils of the *Striatohaplopinites perfectus–Schizosporis permianus* palynological assemblage (PA V after Shelekhova and Golubev, 1993a, 1993b; PA IV after Shelekhova, 1996) are also detected in this marl grading laterally into limestone and sandstone. The bed is 0.02–0.04 m thick.

(35) Gray clay with coal seams and plant remains; the bed is 0.5 m thick.

(36–43) Alternating sandstone, clay, and limestone beds: sandstones are yellowish brown, fine-grained, flaggy, and weakly lithified; clays are brown; gray massive limestones are pierced by a system of thin channels. Rocks yield plant remains and fish scale of *Palaeoniscum kasanense* Geinitz et Vetter and *Acentrophorus varians* (Kirkby). Beds are 1.0–1.1 thick in total.

Beds 2–11 are well traceable in exposures at the right side of the Kama River, 1–2 km upstream off the Tikhie Gory Wharf (Mendeleevsk). At the Site 896 they overlie the following rocks: (2–3) gray bog clay that is horizontally laminated, intercalated with gray sandstone interlayers, and yields lingulid shells, plant detritus, and scale of *Palaeostrugia rhombifera* (Eichwald), *Acropholis* sp., and *Koinichthys ivachenkoi* Esin (6 m); (1) brown massive clay, the apparent thickness of which is 10 m.

CORRELATION

Correlating individual sections in the study region, one should take into account various characteristics of their beds and members, such as lithology, thickness, position in the section, and facies affinity. Similarity in each particular characteristic is however neither necessary nor sufficient criterion for correlation. Even if all the characteristics are comparable, it is impossible to guarantee the correct correlation, because we should bear in mind the widespread phenomenon of lateral facies changes. Consequently, several correlation schemes can be suggested for the studied region, and one of them is shown in Fig. 2. I consider this one as most realistic, because it requires a simplest scenario of its origin. It seems also most compatible with the established arrangement of several reference levels corresponding to important, geologically instant turning points in the regional sedimentation. The gist of this levels and their significance for the Kazanian Stage stratigraphy are principal objectives of this study.

FACIES CHARACTERISTICS

Kazanian deposits of the study region represent a complex facies family of a sea coastal zone with terrigenous sedimentation. The family is composed of continental, lagoonal, bar, and marine facies tracts (Fig. 5).

Open-sea facies tract characterizes sediments that have been deposited below the storm wave base (distal flood-beach zone) and above it (transitional flood-beach zone).[3] Deposits of the former zone are represented by light gray massive detrital limestones, which yield abundant bivalve, gastropod, brachiopod, and bryozoan remains (Bed 16 of the Bondyuga section). These rocks absolutely lacking lamination are intensively bioturbated. They evidently accumulated below the fair weather and storm wave base (Elliott, 1990a). The original clastic texture of the rocks obviously reflects the storm wave impact on sediments, but it is almost completely modified in the course of subsequent bioturbation. In beach zones with low wave energy, which are characteristic of lakes and closed seas, the fair weather wave base is about 5 m deep in average, and the storm wave base varies around the depth of 10 m. Largest waves may affect sediments therewith at the depth of 20 m (Brodskaya, 1952; Elliott, 1990a). The described deposits presumable accumulated within the depth range of 15–20 m.

Brownish gray to brown limestones represent deposits of the transitional flood-beach zone. These rocks are sandy to a various extent and often show horizontal lamination. In their members, thin (5 cm or less) and frequent interlayers of sandy limestones displaying horizontal or wavy lamination alternate with thicker beds (up to 50 cm) of massive limestones with vague lamination and variable bioturbation features. The former, more coarse-grained deposits apparently accumulated in stormy periods, and the latter characterize more quiet sedimentation environments (Elliott, 1990a). Abundant bivalve and brachiopod shells usually occur in coquina interlayers ("shelly pavements").

Deposits under consideration correspond to beds 17–20 and 28–30 of the Bondyuga section and to the

[3] In this work, I use terminology suggested by Elliott (1990a).

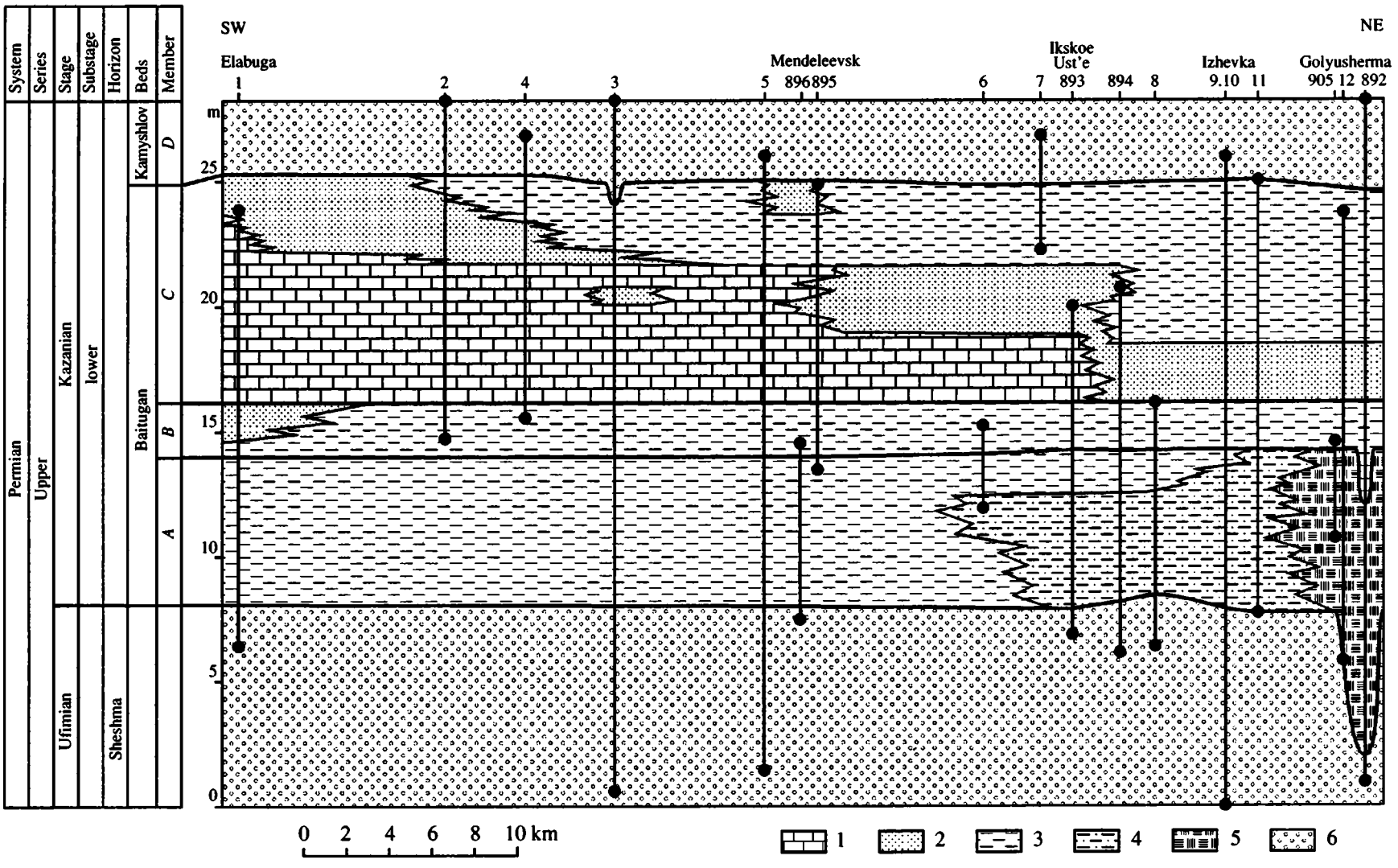

Fig. 5. facies structure of Upper Permian deposits in the Toima–Izh interfluve area (profile is leveled along the base of Member "C"): (1) open-sea facies tract; (2) bar facies tract; (3) lagoonal facies tract; (4) deposits of delta front; (5) deposits of delta plain; (6) continental facies tract.

2.5-m-thick member exposed near the Ikskoe Ust'e village at the right side of the Kama River (Bed 13, Site 893; see Fig. 2). The member and limestone bed 16 of the Bondyuga section characterize the same stratigraphic level. As for the Bondyuga site, it likely characterizes deposits of transitional zone, which accumulated within the depth range of 5–10 m. Near the Ikskoe Ust'e Village, they correspond to deeper facies (10–15 m), because the rocks are more massive here, and indications of their accumulation under wave activity are less frequent (sandy limestone interlayers with horizontal and wavy lamination are rare and thinner). In the last case, sediments were deposited very close to the front of barrier islands (Fig. 5). This bar zone of paleobasin was about 12 km wide and adjacent to the next lagoonal zone of about 55 km wide (Fig. 5). Consequently, limy sediments of Bed 13 accumulated, as I think, about 70 km away from shoreline. Thus, the bottom relief of the early Kazanian basin raised by 10–15 m along the distance of 70 km, i.e., it was very gentle, dipping at the angle of 0.5–0.7'. A relief like this can be observed now in the northern circum-Caspian depression.

Bar facies tract is very characteristic of Kazanian deposits in the study area. The corresponding rocks are yellow and brown fine- to medium-grained sandstones, which are massive or displaying horizontal and cross lamination. A variety of ripple marks is often characteristic of their bedding planes. Coquina interlayers (up to 2–3 cm) composed of bivalve and brachiopod shells are commonly confined to bedding planes separating large sandstone members. Fish scale and carbonized plant remains are also abundant in these rocks. The rocks in question (Golyusherma section, Bed 23; Turaevo section, beds 20, 21, 23; Ikskoe Ust'e site, beds 14–17; Bondyuga section, beds 21–27 and 36–43) accumulated under active hydrodynamic conditions characteristic of rear frontal areas of the flood and lower beach zones (Elliott, 1990a). In the facies profile, they occupy an intermediate position between normal marine and lagoonal deposits that is why I attribute them to the bar but not beach facies. Beach facies adjacent to the land are interconnected with continental facies.

In the Toima–Izh interfluve area, the greater part of the Kazanian Stage is composed of **lagoonal deposits** (Golyusherma section, beds 15–22 and 25–32; Turaevo section, beds 6–19 and 22; Ikskoe Ust'e site, beds 5–12; Bondyuga section, beds 1–14 and 31–35). This facies tract is most diverse in terms of lithology. Clay facies prevail here over marl and limestone facies. Siltstone, fine-grained sandstone, and coal occur in minor intercalations. Predominant gray to dark gray clays are horizontally laminated and intercalated with gray sandstone interlayers. They yield insect remains, fossil bivalves, and lingulid shells, which are locally concentrated in coquina lentils. Yellow or brown, similarly laminated clay varieties are less abundant. These have silty or sandy admixture and yield diverse fish scales. Coal seams are usually confined to these clay facies. Black to dark brown and gray limestones with horizontal or wavy lamination are often foliated, bituminous, having clay admixture. Fossils in these rocks are represented by bivalves (locally abundant), gastropods, ostracodes, conchostracans, brachiopods (rare), calcareous serpulid tubes, fish remains (scales and whole skeletons), and rare bones of terrestrial vertebrates. I noted the inverse relationship between the bituminization degree of rocks and fauna abundance and diversity.

The carbonate–clayey composition of rocks and their fine horizontal lamination suggest calm hydrodynamic environments of sedimentation. Wavy lamination points to periodic influence of wave activity. Consequently, sediments under consideration accumulated in shoal settings. The hydrological regime differed from that of normal marine basin. Judging from character of invertebrate fauna, the water mass was fresh or brackish. Faunal assemblages of low diversity are lacking forms typical of open-sea zones of the Kazanian basin (spiriferids, corals, crinoids, etc.). In contrast, they are rich in euryhaline bivalve, lingulid, ostracode, serpulid, gastropod, and some other taxa. Bivalves prevail over brachiopods and can be highly concentrated in coquina interlayers. In the last case, the host rocks are either light-colored bitumen-free limestones, or light gray clays. A good example of this is the uppermost part of Member "B" known as the *Pseudomonotis garforthensis* Limestone (Bludorov, 1938, 1964) and considered as local reference horizon. This limestone just slightly differs in lithology from limestones of the preceding facies tract, and many researchers used to believe in its marine origin (Noinskii, 1932; Egorov, 1932, Bludorov, 1938, 1964; Forsh, 1951, 1955; Tikhvinskaya, 1955, 1967; Ignat'ev *et al.*, 1970; Esaulova, 1986; Golubev, 1992). Now, I suggest the lagoonal origin of this rock in view of the following data. The limestone bed grades downward into highly bituminous and coaliferous deposits of distinctly lagoonal setting. The latter are weakly bioturbated and depleted in invertebrate fossils, representatives of which are dwarfed; in contrast, whole fish skeletons are quite abundant at this level. These observations suggest the stagnant sedimentation environments characteristic, in particular, of lagoons. In addition, the limestone bed grades into bar sandstone in the west (near Elabuga) and into coaliferous facies (deposits of coastal marshes with lotic waters) in the east. Thus, the *Pseudomonotis garforthensis* Limestone occupies an intermediate position between continental and bar deposits. Its lithological and paleontological similarity with deposits of transitional and flood beach zones is a consequence of sediment accumulation in a past lagoon poorly isolated from open sea. As it is shown below, deposits of Member "B" accumulated under conditions of a minimum sediment influx after the delta elimination "in the east." The deficient sediment influx resulted in wave abrasion of barrier islands located "in the west." As a result, lagoons, which were well isolated, became connected with open sea. Exactly this can be inferred, when one observes the upward lithological changes in Member "B."

The *Pseudomonotis garforthensis* Limestone characterizes the sedimentation period, when lagoons were poorly isolated from the sea.

The basal and topmost portions of Permian succession exposed in the study region are composed of variable **continental facies.** Clays predominant here associate with less abundant medium- to coarse-grained sandstones and subordinate gravelstones and small-pebbled conglomerates. Red color is a characteristic feature of these rocks. Cray-colored deposits infilling the erosional incisions represent an exception, Exactly they are rich in fossils, whereas red beds are almost lacking them. For instance, beds 2–11 of Golyusherma section yielded abundant fish remains, bones of terrestrial vertebrates, shells of fresh-water bivalves, and plant remains.

Most remarkable among continental deposits are deltaic sediments exposed near the Izh River mouth at the right side of the Kama River (Fig. 5). All principal members of deltaic facies family can be recognized here: facies of deltaic lowland, facies of delta front (prodelta), and facies of delta dying out (Elliott, 1990b). The delta plain above water level was dissected by a system of active and inactive streams into dry to semidry land areas and shoals (Elliott, 1990b). Deposits that accumulated in these settings are characteristic of Member "A" of the Kazanian section exposed near the Blagodat' Village. The basal part of the member is composed here of alternating lenticular beds of gray clays, siltstones, and sandstones, the total thickness of which is 4 m (Figs. 2, 3). These are deposits of delta flood plain (clay and siltstone beds with fish remains and leaf impressions) and of small short-lived scoring channels (thin elongated sand and sandstone lentils with horizontal and diagonal lamination, which yield fish remains, tetrapods bones, and fresh-water bivalves). Abundant root casts inside these beds (Fig. 4) suggest periodical exsiccations or episodes of considerably decelerated sedimentation rate.

Upward in the section, there is a comparatively thick sequence of coarse-grained cross-laminated sandstones. These are deposits of the main delta stream.

Farther westward, along the right bank of Kama River between Izhevka and Ikskoe Ust'e villages, there are exposed facies of the delta front (Turaevo section, beds 2–5; Ikskoe Ust'e site, beds 2–4). The basal gray-colored sequence of Member "A" (2.5–3.0 m) consists here of alternating clay, siltstone, and fine-grained sandstone lentils with ripple marks on bedding planes. This sequence grades upward into massive fine-grained sandstones. These deposits accumulated in a lagoonal setting, because they show marks of basinal processes, in particular, of wave activity, thus resembling deposits of fore-frontal flood beach zone. Nevertheless, their local distribution and spatial association with delta plain facies allow me to class them with deposits of delta front. Their succession is of regressive type that is very characteristic of prodelta deposits.

When delta dies out, its plain turns into marshy area favorable for accumulation of coaliferous deposits (Fig. 2). The lowermost coal seam directly above deltaic deposits is highly variable in thickness, suggesting an undulating relief before the accumulation time of coaliferous sediments (Fig. 6). Analyzing the undulation patterns, we can reconstruct disposition of delta-plain lobes at the terminal stage of delta existence. At the point located 1.5 km SSE of the Chernyi Klyuch Village (Fig. 6), the main delta stream bifurcated, and its northern branch flowed toward the Chumali Village. Bifurcation of the latter took place near the Muvazhi Village, 0.7 km southeastward of it, so that one branch extended northwestward across this village, and another one was oriented to the west. The southern branch of the main stream flowed toward the Blagodat' Village parallel to and northerly of the Pervye Prudki Ravine. Then it bifurcated again in front of the Shakhterskii Log Ravine, and its larger offshoot continued to the south, toward the Golyushurma area, leaving aside the termination of the Pervye Prudki Ravine. The lesser sublatitudinal channel was running slightly northward of the Blagodat' Village. Consequently, it was a lobate delta formed predominantly by fluvial activity outside the tideland and under a minor impact of wave actions (Selley, 1989; Elliott, 1990b).

When delta died out, terrigenous sedimentation in lagoonal settings gave place to accumulation of carbonate sediments (Member "B"). Abundance of organic matter and growing isolation were responsible for appearance of stagnant environments in lagoons, where bituminous limy sediments buried the intact fish skeletons. The decreased sediment runoff finally resulted in wave abrasion and subsequent breakup of the barrier island zone, after which lagoons got better connections with open sea.

The described facies tracts regularly replace each other in lateral direction. Detrital and organogenic-detrital limestone facies of open-sea zone grade eastward into loose sandstone facies of bar zone, which, in turn, are replaced by lagoonal facies of clays or marls and foliated bituminous limestones (Fig. 5). Further eastward, the lagoonal facies grade into continental deposits. Similar distribution patterns of different-type facies are characteristic of lower Kazanian deposits in the Volga River middle courses and Kama River lower reaches, as it was noted long ago by Forsh (1951, 1955).

The vertical facies succession is frequently lacking gradual transitions, being irregular in places. Gradation can be observed only between the marine and bar facies of Member "C." In other cases, boundaries separating different lithological varieties of sediments are sharp, and their normal succession is often violated. For instance, the open-sea deposits may directly underlie (Bondyuga section, beds 30, 31) or overlie the lagoonal sediments (the same section, beds 14–16; see also Fig. 5).

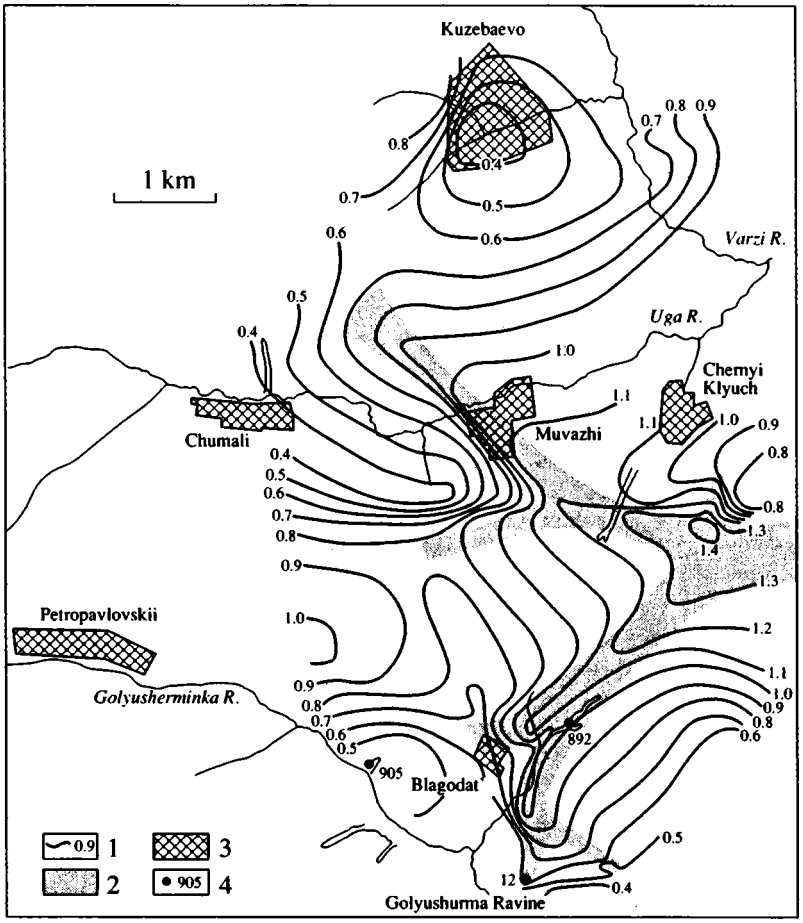

Fig. 6. Reconstructed delta of the early Kazanian time, surroundings of the Blagodat' Village (Alnash district of Udmurtia): (1) isopachs outlining thickness of lower coal seam (after Bludorov, 1938); (2) branches of delta stream; (3) settlements; (4) studied sections.

A MODEL OF KAZANIAN SEA DEVELOPMENT

Sharp and irregular facies changes mentioned above are extremely important indications elucidating the character of Kazanian sea evolution and, as a result, the Kazanian Stage stratigraphy. Both problems are however in need of considering first the known general trends of facies successions in coastal zones of shallow basins with terrigenous sedimentation.

A character of vertical and lateral facies successions in a sea-coastal zone of terrigenous sedimentation depends on many factors. Principal among them are the rate of sediment runoff (sedimentlogical factor), frequency of sea-level oscillations (eustatic factor), and subsidence rate (tectonic factor). The lateral succession of all four facies tracts appears in the section only in the case of a long-term supply of abundant terrigenous material. The vertical facies succession depends on the shoreline migration with time. It would be missing in the case of fixed shoreline position, but situations corresponding to such static shorelines have been hardly ever recognized in geological records (Elliott, 1990a; Selley, 1989).

As a rule, shorelines are mobile to a certain extent, and this mobility results in vertical facies changes. The character of changes is controlled by the rate and direction of shoreline movements, which are highly variable. When transgressive–regressive cycles develop slowly, the vertical transition from one facies to another is gradual (Selley, 1989), displaying alternation of beds characterizing both facies. In contrast, the quick shoreline displacement is responsible for appearance of abrupt stratigraphic boundaries and may disturb the normal facies succession (Johnson and Baldwin, 1990; Selley, 1989). This is a response to paleogeographic changes in sedimentation area, when they are faster than the sedimentation rate. Since this statement is of principal significance, I would like to clarify it by example.

Let us consider a sea-coastal zone of terrigenous sedimentation against the background of compensating subsidence at the rate of 1 mm per 1000 years. Assuming that the bar zone and lagoon are 15 and 40 km wide, respectively, let us take an observation point located 10 km seaward of the former and a following possible

scenario. The shoreline had the quasi-stationary position during few tenth of thousands years, when its offshore and backward displacements were insignificant. During the subsequent regressive phase that lasted several hundreds years, the sea retreated by 80 km, and afterward there was another long-term period of quasi-stationary conditions. In this case, the regional paleogeography must be considerably changed during the short-term regressive phase so that continental sedimentation replaced the marine one in our observation area. This important phase was able to put itself on geological record as a negligible mark only, e.g., as a sedimentary layer less than 1 mm thick. As a result, the section at the observation point would mostly consist of sediments deposited during the quasi-stationary (quiet) periods. Its lower and upper portions would be composed of marine and continental facies, respectively. The vertical facies succession is violated in this case, because sediments of lagoon and bar zones are missing from it. Another important consequence is that the boundary between marine and continental deposits must be abrupt, because they accumulated under very contrast conditions.

Quick transgressions and regressions must always lead to appearance of abrupt stratigraphic boundaries between facies or facies tracts. These boundaries can separate beds of so different lithology that one may erroneously interpret them as indicating break in sedimentation. Actually, it would be a mistake, because we deal in this case not with a break in the process, but with a sharp change in its character.

As for the Kazanian deposits in the Toima–Izh interfluve, the sharp stratigraphic boundaries between their facies tracts and all violations of normal facies succession indicate that quick and recurrent shoreline migrations were very characteristic of the Kazanian sea evolution in the study region. The studied sections exhibit six levels corresponding to periods of most significant reorganizations in paleogeography of the region during the Kazanian time (Fig. 5).

(1) Lower boundary of Member "A"; this level is well manifested almost everywhere in the region, being distinct in facies aspect. The boundary separates the terrestrial red beds of the Ufimian Stage from the Kazanian gray lagoonal deposits. The level is nowhere marked by alternation of lagoonal and continental beds. The only exception is the Blagodat' Village area, where Member "A" consists of continental deposits, the lower boundary of which is locally unclear. A good example is a section exposed in the nameless ravine, the left tributary of the Golyusherminka River 1.5 km upstream off the Takhtashur Creek mouth (Site 905). Lower horizons of Member "A" are composed here of vinous clay that is similar to underlying Ufimian sediments. In other places, where sediments of the member are colored gray (e.g., Site 892), lower boundary of the member is however quite distinct.

The boundary in question corresponds to the Kazanian sea transgression (t_1). In the study region, the shoreline displacement was about 30 km (distance between the Mendeleevsk and Blagodat' sections) (Fig. 1). Moreover, the true magnitude of displacement could be much greater. The boundary is well traceable along the Kama River, downstream off the study region to the Vyatka River mouth. All along this distance, it outlines the top of continental red beds. Farther downstream, these red beds give place to the Bugul'ma Beds of gray sandstone (Esaulova, 1986) of the sea-beech facies type. Accordingly, the displacement magnitude of shoreline could be as great as 90 km.

(2) Boundary between members "A" and "B" is distinct throughout the study region despite its occurrence inside the single, lagoonal facies tract. It reflects changes in sedimentation environments in the period of decreased sediment runoff, appearance of stagnant sedimentation settings, and coastal marsh development "in the east." It was a time of minor transgression (t_2), when shoreline advanced few kilometers inland, and coastal marsh replaced the former dry-land area at the Golyusherma site.

(3) Boundary between member "B" and "C" is also distinct in the whole region. In the west, it separates the marine and lagoonal deposits (an abnormal vertical succession of facies), whereas in the east it is distinguished between the bar and lagoonal facies. The bar deposits are recognized in the upper part of Member "B" in the Elabuga area. At the base of Member "C," their equivalents appear in the Turaevo section and extend to the Blagodat' Village. Consequently, the distance between Elabuga and Turaevo sites (about 40 km) defines the magnitude of inland migration of shoreline (transgression t_3).

(4) Level that separates beds 16 and 17 in the Bondyuga section, beds 13 and 14 at the Ikskoe Ust'e site, and beds 21 and 22 in the Turaevo section is defined as indicator of the first regression phase (r_1). This boundary separates the bar and lagoonal deposits of the Turaevo section and the marine and bar facies at the Ikskoe Ust'e site. In the Bondyuga section, it runs between beds deposited in the marine transitional and distal flood-beach settings. The regression magnitude was about 15 km (the distance between Bondyuga and Turaevo sites).

(5) Boundary between beds 30 and 31 in the Bondyuga section; this boundary separating the marine and lagoonal facies tracts is not very distinct, because the beds are composed of genetically close sediments deposited near the bar zone. The bar facies appear above this level slightly westward off Mendeleevsk. They can be observed in outcrops of the Kama River near the Elabuga (Egorov, 1932) and Naberezhnye Chelny (Zaitsev, 1878). One more exposure with sediments in question is known near the Klyuchevka Ravine at the right side of the Korinka River (right tributary of the Toima River). Below the boundary, a lateral

transition from bar to lagoonal sediments has been observed along the Ikskoe Ust'e–Turaevo profile (Fig. 5). Consequently, the fifth level marks the regression phase (r_2), by which the shoreline moved c.a. 20 km off its former position.

(6) The upper boundary of Member "C" is as distinct as level 1. Throughout the region, it separates gray coastal marine deposits from overlying red beds of continental origin. Red beds overlying this level have been traced along the Kama River to the Sentyak Village (Forsh, 1966; Esaulova, 1986; Silant'ev *et al.*, 1998), where they show initial signs of gradation into coastal-marine deposits. The exact area, where the uppermost lagoonal facies of Member "C" are completely replaced by continental deposits, is unknown yet, and amplitude of the regression phase (r_3) can be estimated just approximately. At any rate, the distance of shoreline displacement was not less than 70 km (distance between the Sentyak and Golyusherma sites).

Thus, in the history of Kazanian sea basin within the study region, there were comparatively long periods, when its shoreline had stable position or migrated slowly. These periods alternated with short-term transgressive and regressive events responsible for quick changes in the regional paleogeography. The distinguished six stages can be considered as three larger ones. The first of the latter corresponds to the deposition time of members "A" and "B." Its commencement corresponded to the quick transgression (t_1) that transformed the continental sedimentation settings into the coastal-marine ones. Afterward, the shoreline position was stabilized for a long time. The whole period can be considered as transgressive, as it terminated with the next large transgression (t_3) that began simultaneously with the second large regressive stage of the basin evolution. Characteristic of this regressive stage was gradual sea retreat from the study region, which consisted of two, somewhat accelerated regression phases (r_1 and r_2). The more significant regression (r_3) was final in the sea history and restored the continental regime of sedimentation in the region. All stages can be united into a high-rank transgressive–regressive cycle of sedimentation signifying the Kazanian transgression peak. Data characterizing the subsequent development of the basin under consideration have not been considered here, but its whole history can be reconstructed on the basis of the Kazanian Stage sections located downstream along the Kama River.

The shoreline migration can be evoked by changes in the sediment runoff (sedimentological factor), by sea-level oscillations (eustatic factor), and by crustal movements of various signs (tectonic factor). The latter were formerly considered as most probable cause of oscillatory shoreline displacements around the Kazanian sea, and consequently, of the cyclic structure of the Kazanian Stage (Forsh, 1955, 1966; Ignat'ev, 1976). I believe, however, that such frequent and abrupt oscillations of large amplitude (contraction of sea basin by dozens or even hundreds kilometers across and concurrent shoaling by tenth of meters) in response to tectonic factor are hardly credible for the epicontinental basin. In addition, the cyclic structure of the Kazanian Stage is similar in structurally different areas of the East European platform, e.g., in the Moscow syneclise and Volga–Ural anteclise (Forsh, 1955, 1966; Ignat'ev, 1976). The impact of sedimentological factor is improbable as well. Any possible change in intensity of terrigenous material supply from surrounding land cannot be responsible for the momentary shoreline displacements by dozens of kilometers and for the necessary cyclicity of sedimentation (Forsh, 1955; Ignat'ev, 1976) within a vast region extending from upper to middle courses of the Volga River, and farther into the Kama River lower reaches (about 500000 square kilometers). Thus, the established transgressions and regressions of the Kazanian sea and the related cyclic structure of the Kazanian Stage were controlled by eustatic sea-level oscillations of the global scale, because the sea was connected in the north with the oceanic water mass.

STRATIGRAPHIC ASPECTS

In terms of geological time, large transgressions and regressions described above are the momentary events. It is clear as well that stratigraphic levels corresponding to these events can be successfully used in practice of stratigraphic subdivision and correlation. Significance of a given level is proportional to the event extensiveness, i.e., to the dimension of area, where we detect the required records. It is an ideal case when we are able to detect a particular level throughout the study region. In fact, it is variably manifested in different areas of the region depending on the concrete combination of sedimentological, paleogeographic (e.g., the basin floor inclination), and tectonic factors. As a rule, boundaries that originated in response to minor sea-level fluctuations are traceable within separate areas (not necessarily adjoining), whereas markers of more extensive events can be of regional to interregional significance. As is shown above, the first, third, and sixth levels distinguished in Kazanian deposits of the study region correspond to shoreline displacements of comparatively high magnitude and, apparently, to quite significant sea-level changes. Accordingly, we may assume it possible to recognize them in all sections of the lower Kazanian Substage and to use these markers even for correlation of remote sections via the intermediate ones. Such an approach is used below for correlation of studied bed successions with the stratotype of the lower Kazanian Substage, the more so as judgments upon the subject are diverse as yet.

The Kazanian Stage stratotype near the Baitugan Village of the Klyavlino district, Samarskaya Oblast' (Sok River head, Fig. 1) has been recurrently described in a series of publications (Forsh, 1951, 1955, 1966; Ignat'ev *et al.*, 1970; Solodukho and Tikhvinskaya,

1977; *Korrelyatsiya...*, 1981; Esaulova, 1996). It is divided into three transgressive–regressive cyclothems known as the Baitugan, Kamyshlov, and Barbashino beds (Forsh, 1951).[4] The lower part of the Baitugan Beds (elements I and II) is composed of the 30-m-thick sequence of bluish gray clay (Fig. 7) that yields abundant shells of *Lingula orientalis* Gol. in association with less abundant brachiopod shells. The sequence is known under the name Lingulid Clay. The overlying coquina bed (2 m) is composed of brachiopod shells associated with bryozoan, crinoid, solitary coral, and bivalve remains (Element III). The topmost marl member of the Baitugan Beds (Element IV) is 6 m thick, characterized by the same, though impoverished, faunas. The Kamyshlov Beds consist of greenish gray clay (3–5 m), bearing lingulids and small bivalves, and of gray marl and dolomite (22 m) with diverse assemblages of marine invertebrates (as compared to Element III of the Baitugan Beds, diversity of fossils is lower, and bivalve remains are more abundant among them). The Barbashino Beds include the lowermost unit of greenish gray clay with rare lingulid shells (9 m). Above this unit, there was distinguished the yellowish gray sandy dolomite (6 m) and sandstone (4 m), both yielding assemblages of brachiopods and abundant bivalves. The overlying deposits are represented by coastal-marine and continental facies of the upper Kazanian Substage.

In opinion of Forsh (1955), the Baitugan Beds include all gray colored deposits of the Toima–Izh interfluve, the upper boundary of which is at the base of Bed 32 in the Golyusherma section, and at the top of Bed 43 in the Bondyuga section (Fig. 2).

Bludorov (1964) divided the lower Kazanian deposits of the study region into seven units: Member I or the Lingulid Clay; Member II or the middle Spiriferid Limestone; members III, IV, and V; Member VI or the upper Spiriferid Limestone; and Member VII. In his opinion, only three lower units are exposed in the Toima–Izh interfluve. Member I (Lingulid Clay) corresponds here to beds 2–19 of the Golyusherma section, to beds 2–7 of the Turaevo section, to beds 2–5 of the Ikskoe Ust'e site, to beds 1 and 2 of the Bondyuga section, and to beds 2–4 of the Tikhie Gory site. Member II (middle Spiriferid Limestone) includes beds 20–22 of the Golyusherma section, beds 8–19 of the Turaevo section, beds 6–13 of the Ikskoe Ust'e site, beds 3–20 of the Bondyuga section, and beds 5 and 6 of the Tikhie Gory site. Member III spans the ranges of beds 23–32 in the Golyusherma locality, 20–23 in the Turaevo section, 14–17 at the Ikskoe Ust'e site, and 21–43 in the Bondyuga section. The overlying, predominantly terrigenous red beds represent, in opinion of Bludorov, the Belebeevo Formation of the upper Kazanian Substage. Consequently, all lithostratigraphic units distinguished by Bludorov have diachronous boundaries.

All the members have been traced far to the south along the Kama River tributaries up to the Sok River head. Bludorov published the isopach maps for the studied deposits without correlation scheme of individual sections. Considering their possible correlation on the basis of published maps (Bludorov, 1964; Figs. 20–26), one would come to the following stratigraphic relationships characterizing the Sok River head: Member I is represented here by gray clay and the *Lingula* Marl (25 m); Member II corresponds to brachiopod limestone (9 m); Member III consists of clay with marl intercalations (15 m); Member IV is of dolomite composition (about 16 m); Member V is composed of brachiopod limestone (about 8 m); Member VI includes marl strata (about 5 m); and Member VII consists of limestone intercalated with marl and clay interbeds (about 7 m). Thus, it is possible to state, thought with reservations, that Bludorov correlated member I and II with the Baitugan Beds, members III and IV with the Kamyshlov Beds, and members V–VII with the Barbashino Beds.

Tikhvinskaya (1967) considered her Member "A" as a unit of the lower Kazanian horizon corresponding, in her opinion, to the first Kazanian cyclothem, i.e., to the Baitugan Beds in the subdivision scheme suggested by Forsh. The middle lower Kazanian members "B" and "C" would correspond in this case to the Kamyshlov Beds and the upper Member "D" to the Barbashino Beds.

In the area under consideration, Ignat'ev *et al.* (1970) distinguished the lower (Kz_1^1) and middle (Kz_1^2) horizons of the Kazanian Stage, the former corresponding to members I and II discussed above, and the latter comprising Member III and overlying deposits of the Belebeevo Formation. In their work, the lower and upper horizons are correlated with the Baitugan and Kamyshlov beds, respectively. This opinion was shared by later researchers (Kalyazin, 1976; Esaulova, 1986).

The cited works show that their authors variably interpreted the boundary level between the Baitugan and Kamyshlov beds placing it at the top of first, second, or third members of the Bludorov's scheme. This variety of opinions clearly demonstrates disadvantages of traditional stratigraphic approach to correlation of distant section by means of tracing beds via intermediate sections. In my opinion, the problem can be solved now with the help of levels marking quick transgressive and regressive event.

Beginning the correlation procedure, we should analyze first the stratotype section of the lower Kaza-

[4] The Baitugan Beds of the stratotype area overlie a sequence of gray fine-grained bituminous sandstones locally saturated with tar ("Shugur Sandstones"). The latter yield scarce foraminifers, ostracodes, lingulids, brackish-water bivalves, and plant remains. Formerly, the Shugur Sandstones were attributed to the Ufimian Stage (Noinskii, 1932; Raspopov, 1932; Forsh, 1955; Bogov, 1977), but in later schemes (Ignat'ev, 1977; *Reshenie...*, 1990) they turned out to be incorporated first in the Bugul'ma Beds (sequence or horizon), and then into the Baitugan Beds of the Kazanian Stage (Esaulova, 1996). In this work, I accept the Ufimian age of the Bugul'ma Beds without special consideration they need in.

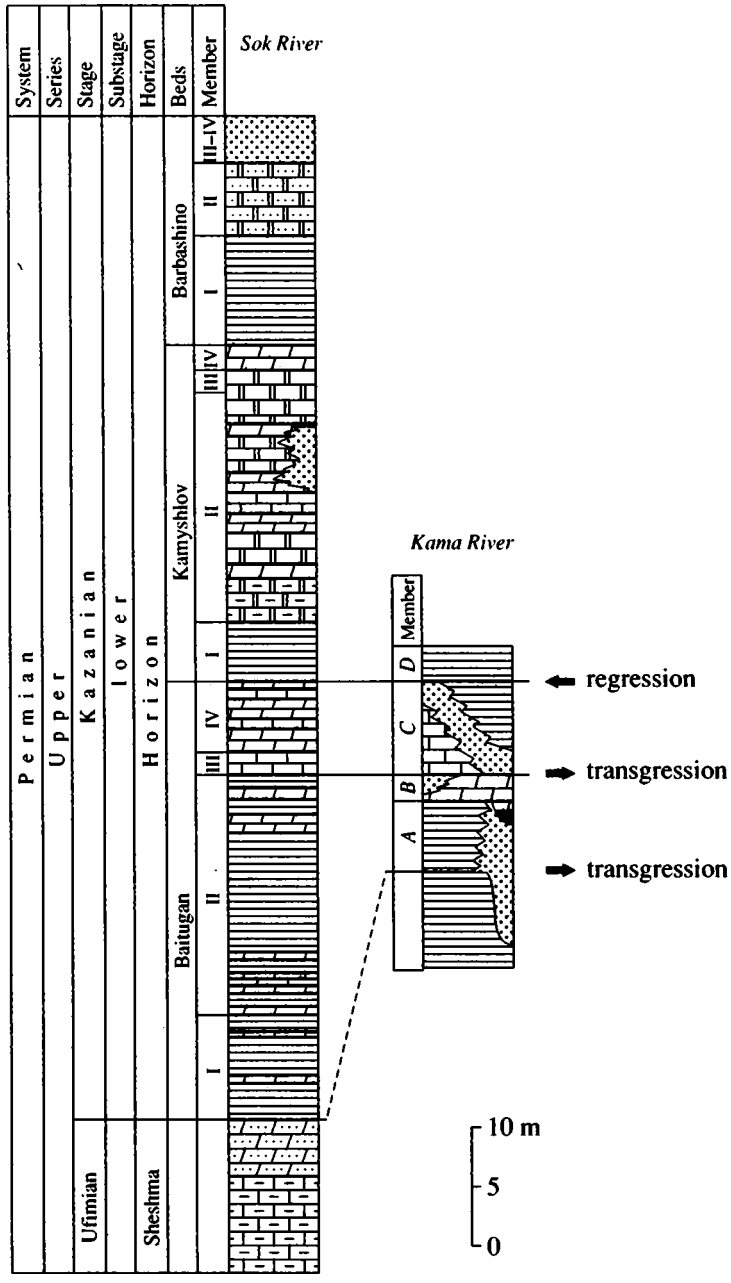

Fig. 7. Correlation scheme for lower Kazanian deposits in the Kama River lower courses and the substage stratotype in the Sok River head, Samarskaya oblast (symbols as in Fig. 2).

nian Substage, where the Baitugan Beds correspond to the peak phase of the Kazanian transgression. Exactly these beds yield abundant and diverse fossils of marine invertebrates showing the least evident affinity with euryhaline taxa (Forsh, 1951, 1955). The lower boundary of the beds is very distinct (Forsh, 1951, 1955; Ignat'ev *et al.*, 1970; Esaulova, 1986), corresponding to an abrupt change in sedimentation characterizing the Bugul'ma and Baitugan periods. The beach sandstone facies that accumulated in the Bugul'ma time yield scarce remains of euryhaline "marine" invertebrates found in occasional localities (Esaulova, 1986). In contrast, deposits of the Baitugan time accumulated in normal marine settings with the diverse invertebrate population. They yield even spiriferids, the most distinct representatives of marine brachiopods, which populated the Kazanian sea and whose occurrence suggests that the sea coast was located far in "the east." Thus, the initial Baitugan period was a time of a considerable (many tenth of kilometers) and quick transgression (T_1). Afterward, the shoreline position was stabilized (elements I and II). Element III corresponds to beds rich in diverse marine fossils found in abundance and observable nowhere else in the region except here. It

marks the peak transgressive phase of the Kazanian sea and yields some taxa suggesting the salinity growth in the basin (the normal salinity was never attained however, because the Kazanian deposits are lacking ammonoids, trilobites, and echinoids, while diversity of coexisting conodonts is low). It is likely as well that the corresponding shoreline migration by dozens of kilometers was not as impressive as before. The lower boundary of Element III is abrupt, indicative of a quick advance of transgression (T_2). During the subsequent period of more stable environments, the shoreline slowly migrated seaward, as it is evident from decreasing diversity of brachiopod assemblages upward in the Element IV section. The fossil assemblage of marine invertebrates from basal clays of the Kamyshlov Beds is much less diverse than that from the Lingulid Clay. Accordingly, the terminal Baitugan time marks a quick regression R_1 that was more extensive than the preceding transgression T_2.

Thus, the Baitugan Beds and gray coastal-marine deposits in the Toima–Izh interfluve show the identical formation histories corresponding to the following event succession (Fig. 7): initial large transgression (t_1 and T_1)—transgression stasis—second quick transgression (t_3 and T_2) of lesser magnitude than the first one ($t_3 < t_1$, $T_2 < T_1$)—peak phase of the Kazanian sea transgression—regression stasis— first large regression (r_3 and R_1) exceeding by magnitude the second transgression ($r_3 < t_3$, $R_1 < T_2$). Sections of both regions recorded the same events in the Kazanian sea evolution: $t_1 \sim T_1$, $t_3 \sim T_2$, and $r_3 \sim R_1$. Accordingly, the lower Kazanian deposits studied in the Kama River basin can plausibly be correlated with the substage stratotype in a following manner (Fig. 7): the base of Member "A" corresponds to that of the Baitugan Beds; basal levels of Member "C" and Baitugan Element III appear to be concurrent; the top of Member "C" corresponds to that of the Baitugan Beds.[5] The suggested correlation scheme is compatible with the Forsh's scheme (1955).

One more point should be noted before conclusion. Available paleontological data do not suggest breaks in sedimentation of the early Kazanian time within the study region, but lithological evidences in favor of such an assumption are quite convincing. Nevertheless, this work shows that distinct lithological boundaries, which can be traced over long distances, may appear within the rock succession even in the case of continuous sedimentation.

CONCLUSION

(1) The Kazanian sea represented a vast shallow basin, where bottom inclination was extraordinary gentle, corresponding to 0.5–0.7' in some places. In the north of the Russian plate, the sea was connected with the open ocean.

(2) Sea level changes in the Kazanian sea have been controlled by eustatic oscillations in the "northern" ocean, and corresponding transgressions and regressions spanned extensive areas (magnitude of the early Baitugan transgression in the Kama River basin was greater than 100 km).

(3) Quick transgressive and regressive phases alternated with longer quasi-stationary periods of shoreline stabilization, when the latter experienced only insignificant (first kilometers) displacements in space.

(4) Deposits of the Kazanian Stage accumulated in quasi-stationary periods, and epochs of quick transgressions and regressions are recorded in their sections as abrupt stratigraphic boundaries. These boundaries are most distinctly manifested in sections of diverse coastal-marine facies, which offer a possibility to reconstruct the history of transgressions and regressions in the Kazanian sea.

(5) In terms of geological time, the recorded transgressive and regressive events were momentary, and boundaries corresponding to them are isochronous, enabling the direct correlation between individual sections.

(6) Three levels separating very contrast lithofacies are recognizable in the Kazanian Stage sections of the Mendeleevsk area in Tatarstan (Kama River lower courses). They correspond to large and quick two transgressions and one regression. The same levels genetically related with the same events are distinguishable in the Kazanian Stage stratotype and thus enable correlation between the Baitugan Beds and gray marine to coastal marine Kazanian deposits in the Kama River lower courses. Red beds overlying the latter are analogues of the Kamyshlov Beds, whereas red deposits below them correspond to the Ufimian Stage.

Reviewers A.S. Alekseev and B.I. Chuvashov

[5] Seven members distinguished by Bludorov (1964) in lower Kazanian deposits of the Kama River sites do not span the entire range of the substage and correspond to the Baitugan (members I–III) and Kamyshlov (members IV–VII) beds only.

REFERENCES

Bludorov, A.P., Coal-Bearing Sediments of the Izhevsk Mouth on Kama River, *Uch. Zap. Kazan. Gos. Univ.*, 1938, vol. 98, books 5, 6: Geologiya, issues 11–12, pp. 83–152.

Bludorov, A.P., *Istoriya paleozoiskogo uglenakopleniya na yugo-vostoke Russkoi platformy* (History of Paleozoic Coal Accumulation on Southeastern Russian Platform), Moscow: Nauka, 1964.

Bludorova, E.A. and Bogov, A.V., Spore-and-Pollen Complexes of Kazanian Stage on the Right-Bank Region of Vyatka River and Their Significance for Mapping, *Permskie otlozheniya respubliki Tatarstan (Materialy respublikanskoi permskoi geologicheskoi konferentsii, 27 fevralya–1 marta 1966 g.* (Permian Sediments of Tatarstan. Materials of Republican Permian Geological Conference, February 27–March 1, 1966), Kazan: Ekotsentr, 1996, pp. 66–70.

Bogov, A.V., Stratigraphical Implication of Spore-and-Pollen Complexes in Permian Sediments on the Territory of

Tatar Republic, *Geologiya Povolzh'ya i Prikam'ya* (Geology of the Volga River Region and Kama River Region), Kazan: Kazan. Univ., 1971, pp. 157–164.

Bogov, A.V., To the Paleontological Characteristic of Ufimian Sediments in the Tatar Republic, *Materialy po stratigrafii verkhnei permi na territorii SSSR* (Materials on Stratigraphy of the Upper Permian on the Territory of the Soviet Union), Kazan: Kazanskii Univ., 1977, pp. 174–181.

Brodskaya, N.G., Botttom Sediments and Processes of Sedimentation in the Aral Sea, *Tr. Inst. Geol. Nauk*, 1952, issue 115, Geol. Ser. (no. 57), pp. 1–104.

Chernomorskii, N., Geological Research of Western Elabuga District of Tatar Republic, *Geologiya i poleznye iskopaemye Tatarskoi respubliki (Sbornik rabot 1927–1930 gg.)* (Geology and Minerals of Tatar Republic. Collection of Works of 1927–1930 years), Kazan: Tatizdat, 1932, pp. 59–78.

Efremov, I.A. and V'yushkov, B.P., Catalog of Locations of Permian and Triassic Ground Vertebrata on the Soviet Union Territory, *Tr. Paleontol. Inst. Akad. Nauk SSSR*, 1955, vol. 46.

Egorov, S.P., Geological Observation of the Right Bank of Kama River from Village Izhevskoe Ust'e to Elabuga Town and Toima River Basin in Its Middle and Lower Reaches, *Geologiya i poleznye iskopaemye Tatarskoi respubliki (Sbornik rabot 1927–1930 gg.)* (Geology and Minerals of Tatar Republic), Kazan: Tatizdat, 1932, pp. 158–175.

Elliott, T., Coasts with Terrigenous Sedimentation, *Sedimentary Environments and Facies*, Reading, H.G., Ed., Oxford (UK): Blackwell, 1986. Translated under the title *Obstanovki osadkonakopleniya i fatsii. T. 1*, Moscow: Mir, 1990a, pp. 192–231.

Elliott, T., Deltas, *Sedimentary Environments and Facies*, Reading, H.G., Oxford (UK): Blackwell, 1986. Translated under the title *Obstanovki osadkonakopleniya i fatsii. T. 1*, Moscow: Mir, 1990b, pp. 144–191.

Esaulova, N.K., *Flora kazanskogo yarusa Prikam'ya* (Flora of the Kazanian Stage in Kama River Region), Kazan: Kazan. Univ., 1986.

Esaulova, N.K., Stratotype of Sok Horizon of the Lower Kazanian Substage near Baitugan Village (Sok River), *Stratotipy i opornye razrezy verkhnei permi Povolzh'ya i Prikam'ya* (Stratotypes and Reference Sections of the Upper Permian in Volga River Region and Kama River Region), Kazan: Ekotsentr, 1996, pp. 70–77.

Esin, D.N. and Mashin, V.L., Ichthyolites, *Stratotipy i opornye razrezy verkhnei permi Povolzh'ya i Prikam'ya* (Stratotypes and Reference Sections of the Upper Permian in the Volga River and Kama River Regions), Kazan: Ekotsentr, 1996, pp. 270–293.

Esin, D.N., Early Kazanian Palaeoniscids from the North European Part and Kama River Basin of Russia, *Paleontol. Zh.*, 1995, no. 2, pp. 119–132.

Forsh, N.N., Central and Eastern Parts of the Russian Platform: Upper Permian, *Stratigrafiya SSSR. Permskaya sistema* (Stratigraphy of the Soviet Union), Moscow: Nedra, 1966, pp. 70–117.

Forsh, N.N., Permian Sediments: Ufimian Formation and Kazanian Stage, *Tr. Vses. Nauchno-Issled. Geol.-Razved. Inst., Nov. Ser.*, 1955, issue 92, pp. 1–156.

Forsh, N.N., Stratigraphy and Facies of the Kazanian Stage in the Middle Volga River Region, *Tr. Vses. Nauchno-Issled. Geol.-Razved. Inst., Nov. Ser.*, 1951, issue 45, pp. 34–80.

Golubev, V.K., The Golyusherma Locality of Lower Kazanian Tetrapods (Udmurtiya), *Byull. Mosk. O–va Ispyt. Prir., Otd. Geol.*, 1992, vol. 67, issue 3, p. 131.

Ignat'ev, V.I., *Formirovanie Volgo-Ural'skoi anteklizy v permskii period* (Formation of the Volga-Urals Anteclise during the Permian), Kazan: Kazan. Univ., 1976.

Ignat'ev, V.I., Bugul'ma Horizon of the Lower Kazanian Substage in the Russian Platform, *Materialy po stratigrafii verkhnei permi na territorii SSSR* (Materials on the Upper Permian Stratigraphy in the Soviet Union), Kazan: Kazan. Univ., 1977, pp. 220–233.

Ignat'ev, V.I., Giletin, A.M., Urasina, E.A., and Kalyazin, L.N., New Data on Stratigaphy of Kazanian Sediments in the Cupriferous Zone of the Tatar Republic, *Materialy po geologii vostoka Russkoi platformy*, (Materials on Geology of the Eastern Russian Platform), Kazan: Kazan. Univ., 1970, issue 3, pp. 76–111.

Johnson, G.D. and Baldwin, K.T., Shallow Seas with terrigenous Sedimentation, *Sedimentary Environments and Facies*, Reading, H.G., Ed., Oxford (UK): Blackwell, 1986. Translated under the title *Obstanovki osadkonakopleniya i fatsii*, Moscow: Mir, 1990, vol. 1, pp. 280–342.

Kalyazin, L.N., To the Problem of Stratigraphic Level of Elabuga Limestone, *K kharakteristike paleozoya i mezozoya vostoka Russkoi platformy* (To the Characteristic of Paleozoic and Mesozoic of the Eastern Russian Platform), Kazan: Kazan. Univ., 1976, pp. 88–96.

Korrelyatsiya raznofatsial'nykh razrezov verkhnei permi severa Evropeiskoi chasti SSSR (Correlation of the Upper Permian Different-Facies Sections in the North European Part of the Soviet Union), Leningrad: Nauka, 1981.

Noinskii, M.E., Concise Outline of Investigation History of the Earth's Interiors in the Tatar Republic, *Geologiya i poleznye iskopaemye Tatarskoi respubliki (sbornik rabot 1927–1930 gg.)* (Geology and Minerals of Tatar Republic), Kazan: Tatizdat, 1932, pp. 7–75.

Noinskii, M.E., Report on Geological Research in the Region of Izhevsk Mineral Spring in Summer, 1923, *Izhevskii istochnik* (Izhevsk Spring), Kazan: Tatnarkomzdrav, 1924, pp. 26–51.

Raspopov, G., Geological Research in the Upper Reaches of the Sheshma River, the Bugul'ma District of the Tatar Republic, *Geologiya i poleznye iskopaemye Tatarskoi respubliki (Sbornik rabot 1927–1930 gg.)* (Geology and Minerals of the Tatar Republic, Collection of Works of 1927–1930), Kazan: Tatizdat, 1932, pp. 3–27.

Resheniya Mezhvedomstvennogo regional'nogo stratigraficheskogo soveshchaniya po srednemu i verkhnemu paleozoyu Russkoi platformy s regional'nymi stratigraficheskimi skhemami, Leningrad, 1988. Permskaya sistema, Resolutions of the Interdepartmental Regional Stratigraphic Conference on the Middle and Upper Paleozoic of the Russian Platform and Regional Stratigraphic Schemes, Leningrad, 1988: Permian System, Leningrad: Vses. Geol. Inst., 1990.

Selley, R.C., *Ancient Sedimentary Environments*, Ithaca, New York: Cornwall Univ. Press, 1978. Translated under the title *Drevnie obstanovki osadkonakopleniya*, Moscow: Nedra, 1989.

Shelekhova, M.N. and Golubev, V.K., Early Kazanian Palynological Assemblages from the Lower Kama River Region, *Byul. RMSK po Tsentru i Yugu Russkoi platformy*, 1993, no. 2, pp. 86–89.

Shelekhova, M.N. and Golubev, V.K., Palynological Assemblages and Tetrapod Remains in Kazanian Sediments of the Stratotype Region, *Palinologiya i problemy detal'noi stratigrafii. Tez. VII Palinol. konf.* (Palynology and Problems of Detailed Stratigraphy. Abstracts of Papers for Palynological Conference), Saratov: Saratov. Univ., 1993, pp. 97–98.

Shelekhova, M.N., Palynological Characteristic of the Kazanian Stage, *Stratotipy i opornye razrezy verkhnei permi Povolzh'ya i Prikam'ya* (Stratotypes and Reference Sections of the Upper Permian in the Volga and Kama River Regions), Kazan: Ekotsentr, 1996, pp. 351–364.

Silant'ev, V.V., Zharkov, I.Ya., Sungatullin, R.Kh., and Khasanov, R.R., *Mezhdunarodnyi simpozium "Verkhnepermskie stratotipy Povolzh'ya". Putevoditel' geologicheskoi ekskursii* (International Symposium on Upper Permian Stratotypes in the Volga River Region. Guidebook to Geological Excursion), Kazan: Kazanskii Univ., 1998.

Solodukho, M.G. and Tikhvinskaya, E.I., Grounds for Subdivision of the Kazanian Stage into Horizons, *Materialy po stratigrafii verkhnei permi na territorii SSSR* (Materials on the Upper Permian Stratigraphy in the Soviet Union), Kazan: Kazan. Univ., 1977, pp. 187–219.

Tikhvinskaya, E.I., A Problem of Permian Stratigraphy (on the Range and Lower Boundary Character of the Kazanian Substage in Tatar Republic), *Uch. Zap. Kazan. Gos. Univ.*, 1955, vol. 115, book 16: Geology, issue 23, pp. 37–58.

Tikhvinskaya, E.I., Kazanian Stage *Geologiya SSSR. T. XI. Povolzh'e i Prikam'e. Ch. 1. Geologicheskoe opisanie* (Geology of the Soviet Union, vol. 11: Volga and Kama River Regions, part 1: Geological Description), Moscow: Nedra, 1967, pp. 369–395.

Zaitsev, A., Geological Section along the Kama River Banks from the Village of Usol'ye to the Town of Elabuga, *Tr. O–va Estestvoispyt., Imperat. Kazan. Univ.*, 1878, vol. 7, no. 2, pp. 1–47.

Stratigraphy and Geological Correlation, Vol. 9, No. 5, 2001, pp. 473–482. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 9, No. 5, 2001, pp. 59–68.
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Ammonite Zonation and Interregional Correlation of the Induan Stage

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Abstract—The central Himalayas and the Salt Range are type areas of the lower and upper Induan substages, respectively. The lower Induan Substage spans the interval of *Otoceras* and *Ophiceras* beds. The *Otoceras* Beds in the range of *concavum* and *boreale* zones are most complete in the Boreal region. The *woodwardi* Zone representing the basal Triassic unit in the Tethyan region corresponds to an upper part of the *boreale* Zone coupled with a basal portion of the *Ophiceras* Beds of the Boreal region. The upper Induan Substage begins at the appearance level of meekoceratids, the first Triassic ammonoids having a flattened ventral side. This level is easily traceable in the Tethyan and Boreal sections. The upper Induan boundary is recognizable within lower horizons of the Ceratite Sandstone (basal portion of the *flemingianus* Zone) and at the base of the *hedenstroemi* Zone of the Boreal region. The Induan ammonite successions of central Himalayas, Kashmir, Nepal, Salt Range, Arctic Canada, and Siberia are described, and a scheme of their zonal correlation is suggested.

Key words: Lower Triassic, Induan Stage, ammonite zonation, correlation.

Several schemes of the Lower Triassic stage subdivision are known at present, though many of them found no acceptance among scholars. Some of the recognized stages had not been taken on, and some others happened to be of local usability only.

Two of the schemes turned out to be popular however. In Russia, the Lower Triassic is traditionally divided into the Induan and Olenekian stages, as it was originally suggested over 40 years ago by Kiparisova and Popov (1956). Another scheme that is widely accepted has been put forward by Tozer (1965, 1967) who distinguished four Lower Triassic subdivisions in the Arctic Canada: the Griesbachian, Dienerian, Smithian, and Spathian stages. The former two subdivisions correspond to the Induan, and others to the Olenekian Stage.

At the beginning of the 1980s, the Triassic Commission of the Interdepartmental Stratigraphic Committee of the USSR recommended to use the Induan and Olenekian as the standard stages (Zhamoida *et al.*, 1982). In 1991, this decision was authorized by the Triassic Subcommission of the International Stratigraphic Commission in Lausanne (Visscher, 1992).

Kiparisova and Popov (1956) originally referred the rock succession of central Himalayas and Salt Range to the Induan Stage stratotype. In their last version of the stage subdivision, they considered as such only the Salt Range section, believing erroneously that the *Ophiceras connectens* Zone is the stratigraphic equivalent of the *Otoceras* and *Ophiceras* beds in Himalayas (Kiparisova and Popov, 1964). I think it more reasonable to take the central Himalayas for the lower Induan stratotype area, and to consider the Salt Range as that of the upper Induan, because the first biozonation of the Lower Triassic was elaborated at the end of 19th century exactly in these two areas (Mojsisovics *et al.*, 1895).

It is a common tradition to place the lower Triassic boundary at the base of the *Otoceras* Beds. The beds yield ammonoids of this genus, which were discovered first over a century ago above the Permian Kuling Shales exposed in the Shalshal Cliff near the Niti Pass in central Himalayas (Griesbach, 1880). Later on, these ammonoids were found in other areas of Himalayas (Spiti, Kashmir, Nepal, and southern Tibet), and also in Greenland, Alaska, Spitsbergen, Siberia, and Canadian Arctic Islands.

Almost as long as a century, nobody doubted stratigraphic significance of the *Otoceras* Beds, but experts in conodonts did this recently, trying to shatter the old tradition. They suggest to place the lower Triassic boundary at the first occurrence level of *Isarcicella parva* (Kozur et Pjatakova), assuming that this event either predated the *woodwardi* phase (Kozur, 1998), or happened at the time of its termination (Yin and Tong, 1998). In any case, the boundary turns out to be inside the *Otoceras* Beds thus losing its former definitude. In my opinion, these are mere attempts to substitute the conodont scale for the ammonite one (Shevyrev and Lozovskii, 1998; Shevyrev, 1999a, 1999b, 2000).

Considering below the most complete sections of the Induan Stage, I hold the traditional opinion that the lower Triassic boundary is at the base of the *Otoceras* Beds.

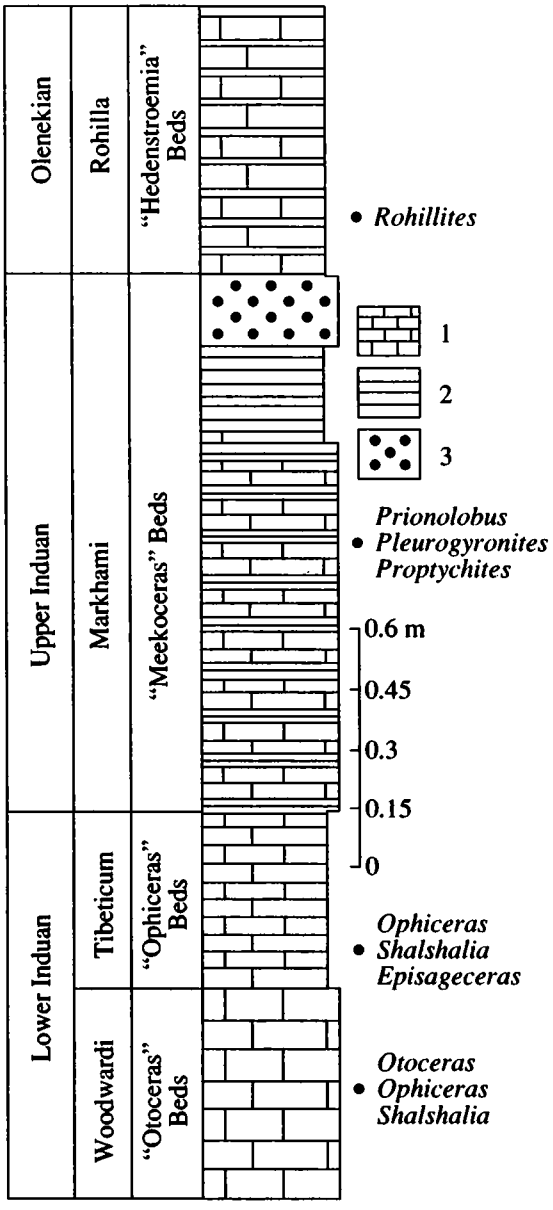

Fig. 1. Stratigraphy of the lower Induan Stage, the Spiti section of Central Himalayas (after Krafft and Diener, 1895; Diener, 1912; Bhatt and Joshi, 1981): (1) limestone; (2) shale; (3) sandstone.

TETHYAN SECTIONS

As is already mentioned, the Induan ammonoid zonation is based on succession of these faunal remains studied over a century ago in the Salt Range and Central Himalayas (Griesbach, 1880; Waagen, 1895; Diener, 1897).

Central Himalayas. Basal Triassic deposits of this region are subdivided into the *Otoceras woodwardi* and *Ophiceras tibeticum* zones of the lower Induan. Griesbach (1880) was first to identify both index species in the Shalshal Cliff exposure. The sequence of *Otoceras–Ophiceras* beds is here about 1 m thick. Its lower constituent rock is black limestone (0.3 m) that yields *Otoceras woodwardi* Griesbach, *Metotoceras dieneri* Spath, *Ophiceras tibeticum* Griesbach, and *Episageceras dalailamae* Diener. The overlying shale (0.4 m) bears *E. dalailamae* and *Pseudoproptychites scheibleri* (Diener). The upper black limestone (0.15 m) yields *Otoceras woodwardi, Ophiceras sakuntala* Diener, and *O. tibeticum* (Diener, 1912; Kummel, 1972). All the rocks also yield *Shalshalia himalayana* (Griesbach), *Vishnuites pralambha* Diener, and *Anotoceras nala* (Diener). It is difficult to distinguish the basal standard zones in the Shalshal Cliff, because their guide fossils are present in both the lower and upper limestone beds. Recently however, it was assumed that the upper limestone bears the redeposited shells of *O. woodwardi* (Bhatt and Arora, 1984).

The Lilang or Dalung (Spiti) site of Himalayas is similarly well known owing to its ammonoid fauna. The *Otoceras–Ophiceras* beds of the site include the basal limestone (0.12 m) with *Otoceras woodwardi, Anotoceras nala, Episageceras dalailamae*, and *Ophiceras sakuntala*, above which there are barren sandy limestone (0.46 m) and upper fossiliferous limestone (0.42 m) that yields *Ophiceras tibeticum, O. sakuntala, Bernhardites ? radians* (Krafft), and *Claraia* forms (Diener, 1912). In 1976, Bhatt and Joshi (1981) studied a similar ammonoid succession at the right side of the Lingti dry valley opposite the Lalung Village. At this locality, a dense massive limestone (0.54 m), the basal one in the *Otoceras–Ophiceras* Beds, yielded *Otoceras woodwardi, Ophiceras* sp., and *Shalshalia himalayana*, whereas gray flaggy limestone (0.44 m) overlying it produced *Ophiceras* sp., *Sh. Himalayana, Episageceras dalailamae, "Flemengites"* sp. (*Bernhardites*, I guess) and *Claraia* forms (Fig. 1). The *woodwardi* (lower limestone with *Otoceras* and *Ophiceras* species) and *tibeticum* zones (upper limestone yielding *Ophiceras* forms, but lacking *Otoceras* species) are as well distinguishable here as in the previous section. Revising the Spiti site later on, Krystyn and Orchard (1996) identified, in addition to mentioned taxa, *Discophiceras* cf. *wordiei* (Spath) and *Bukkenites* sp., which play an important role in correlation of Tethyan and Boreal ammonite successions. In all the considered localities, the Triassic limestones discordantly overlie the Permian Kuling Shale. In the Lingti section, this level is additionally marked by appearance of limonitized pebbly bed 0.10–0.12 m thick.

As is well known (Noetling, 1905; Krafft and Diener, 1909; Diener, 1912), the *Ophiceras* Beds (*tibeticum* Zone) of Central Himalayas are overlain by the *Meekoceras* and *Hedenstroemia* beds, which are most representative in the Lilang and Spiti sections (Fig. 1). Limestones of the *tibeticum* Zone underlie here lumpy limestones and shales (1 m) bearing *Prionolobus, Pleurogyronites, Fuchsites, Lilastroemia, Lilangia, Ambites, Radioceras, Colchenoceras ?, Kingites, Meekophiceras, Proptychites, Clypeoceras, Kymatites,*

Shevyrevoceras, Clypites, Aspitella, and *Himoceras* forms. These *Meekoceras* Beds correspond to the *Prionolobus markhami* Zone overlain by shale (0.25 m) and sandstone (0.18 m) strata lacking determinable ammonoids.

The above rock succession underlies lumpy limestone (1.7 m) with thin shale intercalations. The limestone represents *Hedenstroemia* Beds corresponding to the *Flemingites (= Rohillites) rohilla* Zone of the Olenekian Stage.

Kashmir. In the Guryul Ravine eastward of the Srinagar, Kashmir, the *Otoceras* and *Ophiceras* beds are more than 16 m thick. This site initially studied in the late 19th and early 20th centuries was recurrently revised since 1969 by Japanese and Hindustani geologists (Nakazawa *et al.*, 1975; Bando, 1981; Nakazawa, 1981, 1993; Nakazawa and Kapoor, 1981; Kapoor, 1992, 1996).

The Permian Zewan Formation is crowned in the ravine by sandy limestone. The overlying Khunamuh Formation consists of alternating limestone and shale beds. The formation is divided into several members showing variable proportions between two rock varieties. In the lower Member E that is 18.6 m thick (beds 47–70), shales are intercalated with limestone interlayers. Three subunits of the member differ from each other in the shale types.

The lower unit E_1 (beds 47–51, 2.6 m thick in total) consists of dark gray to black shales with thin lenticular limestone intercalations. The rocks yield small Permian brachiopods, bivalves, occasional foraminifers, partially preserved conodonts, and poorly determinable ammonoids (xenodiscids or ophiceratids and presumable *Hypophiceras* forms). This part of the section is distinguished as the *Hypophiceras ?* Zone.

The middle unit E_2 (beds 52–59, 6.1 m thick in total) is composed of black and dark gray shales intercalated with limestone interlayers. The latter yield *Otoceras woodwardi, Lytophiceras bandoi* Waterhouse, *L. nakazawai* Waterhouse, *Shalshalia himalayana* (Griesbach), *Bernhardites lissarensis* (Diener), and *Pseudoproptychites scheibleri* (Diener). The unit represents the *woodwardi* Zone.

The upper unit E_3 (beds 60–70, 9.9 m thick in total) corresponds to black shales less laminated than those of unit E_2 and intercalated with limestone interlayers. In the lower part of the unit, ammonoids are represented by *Ophiceras tibeticum* Griesbach, *O. paraserpentinum* Waterhouse, and *Metophiceras kapoori* Waterhouse. The *tibeticum* (beds 60–64) and *Ophiceras* sp. (beds 65–70) zones are recognized in its upper part.

The overlying sequence consists of alternating shale, limestone, and sandstone beds, which are divided into five members (from *F* to *J*). Two lower members are of the Induan age. Alternating limestone and shale beds 71–77 (18 m thick in total) of Member *F* yield *Clypeoceras, Proptychites, Paranorites, Vishnuites*, and *Kummelia* forms (*Paranorites–Vishnuites* Zone). *Prionites* and *Radioceras* species are characteristic of Member *G* (beds 78–85, which are 36.4 m thick in total), where limestone is intercalated with shale interlayers (*Prionites–"Koninckites"* Zone). Next Member *H* (beds 86–91) is composed of limestone, shale, and sandstone beds (43.1 m thick in total). Its basal portion (11.1 m) of limestone and shale beds host ammonoids of *Proptychites, Owenites, Kashmirites, Anakashmirites, Wasatchites*, and *Meekoceras* genera (*Owenites–Kashmirites* Zone). This assemblage is characteristic of the basal Olenekian Stage.

Nepal. The most complete Lower Triassic section with extremely abundant fossils have been described in the Marsyangdi River head, northern Nepal (Waterhouse, 1994, 1996a, 1996b). It is located northward of the Braga Village in the Chulu massif.

The Upper Permian limestones and shales of the Marsyangdi Formation are overlain here with a minor hiatus by dolomitic carbonate rocks of the Pengba Member (0.35 m), which are orange-red to yellowish brown at the weathered surface. The lower part of the member (0.25 m) yields *Otoceras woodwardi, Bernhardites lissarensis*, (Diener), *Shevyrevoceras ellipticum* (Diener), *Zakharovites (= Tompophiceras) zakharovi* Waterhouse, *Lytophiceras bandoi* Waterhouse, *Shalshalia himalayana* (Griesbach), and *Pseudoproptychites* aff. *scheibleri* (Diener). The upper one (0.10 m) bears *Metotoceras dieneri* Spath and *Shalshalia himalayana* (Griesbach). The Pengba Member represents the *woodwardi* Zone, where the *dieneri* Subzone is distinguishable.

The overlying Chegadji Member of gray massive limestones (1.2 m) is reddish at the weathered surface. Its basal part (0.7 m) yields *Bernhardites delectus* Waterhouse and *Lytophiceras ptychodes* (Diener). *Ophiceras* and *Lytophiceras* forms are characteristic of the middle interval (0.20 m), and ammonoids of the upper interval (0.30 m) are represented by *Pseudosageceras* sp., *Metophiceras kapoori* Waterhouse, *Bernhardites delectus* Waterhouse, *Altoconchella delinquens* Waterhouse, *Tilichonia typus* Waterhouse, *Ophiceras tibeticum* Griesbach, *O. paraserpentinum* Waterhouse, *Lytophiceras chamunda* (Diener), *L. medium* (Griesbach), *L. ptychodes* (Diener), *Vishnuites pralambha* Diener, *Himophiceras spathi* Waterhouse, *Gyronites chigajiensis* Waterhouse, *Ambites* sp., *Mesokantoa alta* Waterhouse, *M. lichuanensis* Waterhouse, *Zhaojinkeoceras nepalense* Waterhouse, *Kymatites attenuatus* Waterhouse, and *Pseodoproptychites* aff. *scheibleri* (Diener). The Chegadji Member is distinguished as the *tibeticum* Zone with the basal *ptychodes* Subzone.

Both members are constituents of the Pangjang Formation. Waterhouse (1994) referred this formation to the Gangetian Stage using the half-forgotten name of this stratigraphic interval that was introduced by Diener and Waagen more than a century ago (see in Mojsisovics *et al.*, 1895).

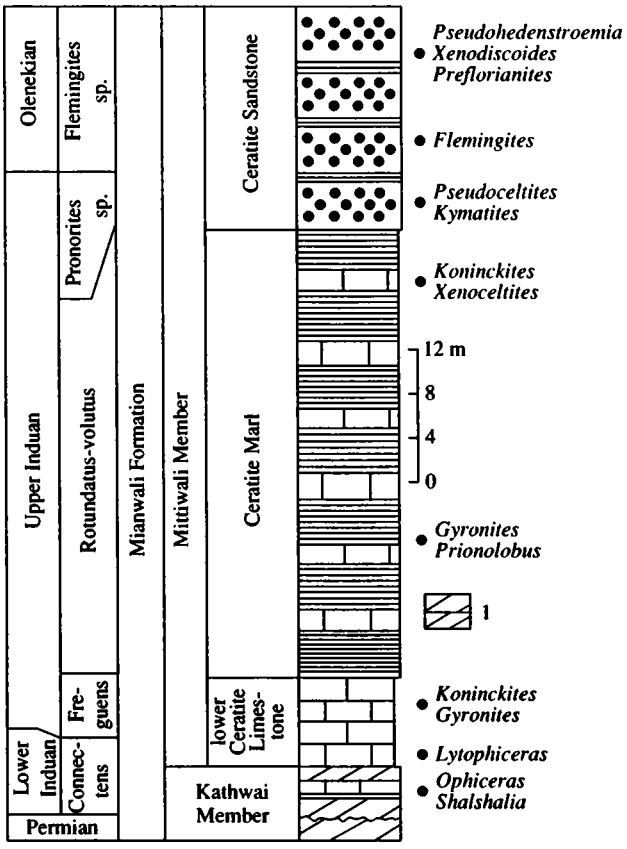

Fig. 2. Stratigraphy of the upper Induan, the Nammal Canyon of the Salt Range (after Waagen, 1895; Kummel and Teichert, 1970; Guex, 1978): (1) dolomite; other symbols as in Fig. 1.

Exposed above are gray, reddish at the surface dolomitic limestones of the Sabche Member (0.3 m) with *Gyronites, Lilangia, Gyrolecanites, Radioceras, Kingites, Paranorites, Koninckites, Clypeoceras*, and *Aspitella* forms (*Gyronites frequens* Zone). In the lower part of the overlying white sugar-like limestones of the Jargeng Member (0.3 m), there were detected *Himoceras, Gyrophiceras, Lilangia, Radioceras, Khangsaria, Xenodiscoides, Proptychites, Ussuriceras, Vavilovites*, and *Koninckites* species. The upper part of this member yields ammonoids of *Gyronites, Khangsaria, Radioceras, Kymatites*, and *Proptychites* genera (*Proptychites abundance* Zone). In the topmost interval of the member, there were found *Prejuvenites, Lilangia, Radioceras, Proptychites, Kingites*, and *Lilastroemia* forms (*Kingites elegans* Zone or Subzone). The overlying Kangla Member (0.5 m) is composed of dense dolomitic limestones reddish at the surface and intercalated with shales. Ammonoids from this member belong to *Gyrophiceras, Gyronites, Pleurogyronites, Gyrolecanites, Lilangia, Radioceras, Khangsaria, Wyomingites ?, Proptychites, Paranorites, Koninckites, Clypites*, and *Clypeoceras* genera (*Pleurogyronites jomsomensis* Zone).

The Sabche, Jargeng, and Kangla members represent the Khangsar Formation, an equivalent of the Annapurnan Stage (Waterhouse, 1996a).

Salt Range. This and Surghar ranges of western Pakistan are known as stratotype areas of the upper Induan Substage. The Triassic succession begins here with the Mianwali Formation that is up to 200 m thick (Fig. 2). The basal Kathwai Member of the latter (1.5–6.5 m) is composed of dolomite and limestone beds intercalated with shale and sandstone interlayers (Kummel and Teichert, 1966, 1970; *Pakistani–Japanese Research Group*, 1986). The lower part of the member yields Permian brachiopods, foraminifers, and bryozoans. In the middle and upper intervals, Kummel (1970) identified scarce ammonites *Shalshalia himalayana* (Griesbach) and *Ophiceras connectens* Schindewolf, which characterize the local *connectens* Zone (Guex, 1978).

The next Mittiwali Member includes the lower limestone–marl–sandstone sequence with ceratite remains and the upper Ceratite Limestone (Waagen, 1895). The type locality of the member is near the Chidru Village, where this unit is 88 m thick. The member thickness is maximal (163 m) in the Surghar Range.

The lower Ceratite Limestone (actually the coquina bed 2–8 m thick) is composed of fragmented ammonoid, bivalve, and gastropod shells. *Shalshalia* and *Lytophiceras* forms were identified near its base (Guex, 1978). Ammonoids occurring above the basal level belong to *Pseudosageceras, Gyronites, Gyrolecanites, Radioceras, Ambites, Prionolobus, Gyrophiceras, Koninckites, Wanguikangia, Bernhardites, Hediscus, Proptychites*, and *Ovaliconcha* genera (Waagen, 1895; Waterhouse, 1994). This diverse ammonoid assemblage characterizes the *Gyronites frequens* Zone.

The Ceratite Marl (up to 40 m thick) is actually shale with lenticular intercalations of clayey limestone. The latter yields abundant ammonoids of genera *Gyronites, Kingites, Prionolobus, Koninckites, Kymatites, Proptychites, Paranorites, Collignonites, Prejuvenites, Xenodiscoides, Ambites, Xenoceltites, Paraspidites, Clypites, Radioceras, Ussuriceras, Shevyrevoceras, Waagenoproptychites, Eoptychitoides*, and *Latisageceras*. The unit is divided either into the *Proptychites lawrencianus* and *P. trilobatus* zones (Waagen. 1895; Mojsisovics *et al.*, 1895), or into the *Prionolobus rotundatus, "Celtites" (= Shevyrevoceras) fallax*, and *Koninckites volutes* zones (Noetling, 1905).

The Ceratite Marl grades upward into the Ceratite Sandstone (15–30 m) of bedded to massive structure. The last unit is remarkable owing to presence of large (up to 65 cm across) *Flemingites* shells associated with bellerophontoid gastropods *Stachella*. The *Stachella*-bearing horizon in the middle of the unit divides it into lower and upper parts. The lower one yields ammonoids of *Pseudoceltites, Kymatites, Pleurogyronites, Paranorites, Gyrophiceras, Preflorianites, Xeno-*

discoides, Koninckites, Khangsaria, and *Radioceras* genera. Representatives of genera *Flemingites, Clypeoceras, Prionites, Xenoceltites, Pseudoceltites, Xenodiscoides, Preflorianites, Pseudohedenstroemia, Paranorites*, and *Beoflemingites* are known from the lower subunit. The level with *Stachella* shells is also marked by species of genera *Flemingites, Rohillites, Pseudoflemingites, Clypeoceras, Paraspidites, Eoptychites, Koninckites, Fuchsites, Waagenoproptychites, Paranorites, Parakymatites, Parastephanites, Pseudoceltites, Kashmirites, Anakashmirites, Xenodiscoides*, and *Heibergites* (Waagen, 1895; Kummel and Steele, 1962; Waterhouse, 1996a).

On the basis of this succession, Waagen distinguished the "*Ceratites*" (= *Pseudoceltites*) *normalis, Flemingites radiatus*, and *F. flemingianus* zones of the Ceratite Sandstone. Noetling (1905) believed however that this unit characterizes the *flemingianus* Zone only despite the fact that first *Flemingites* forms appear at the occurrence level of *Stachella* shells, and that the zonal index species is characteristic of the upper sandstone interval. Nevertheless, his viewpoint was shared in many subsequent works, but later on the Pakistani–Japanese research group decided after all to subdivide the Ceratite Sandstone into the lower *Paranorites* sp. and upper *Flemingites* sp. zones (Ali *et al.*, 1985).

BOREAL SECTIONS

The most complete and well-studied boreal sections of the Induan Stage are known in Arctic Canada and Siberia.

The Induan Stage is chronological equivalent of the Griesbachian and Dienerian stages distinguished in the Axel Heiberg and Ellesmere islands of Arctic Canada (Tozer, 1965, 1967, 1994). The stages span a succession of shale, siltstone, and sandstone beds of the Blind Fiord Formation subdivided into the Confederation Point, Smith Creek, and Svartfjeld members (Embry, 1986). Each member begins with shale beds grading upward into siltstones and sandstones. The *Otoceras concavum, O. boreale, Ophiceras commune, Bukkenites strigatus* zones are distinguished in the lower member corresponding to the Griesbachian Stage. Stratotypes of the stage and of the *concavum, boreale*, and *strigatus* zones are situated in the Griesbach River basin, the Axel Heiberg Island. The upper *Ophiceras* Beds in the Stosch Cape of eastern Greenland represent stratotype of the *commune* Zone.

The lower zone is known in its stratotype area only, where it yields ammonoid species *Otoceras gracile* Tozer and *O. concavum* Tozer. *Otoceras boreale* Spath appears at the level of 32.9–36.6 m above the stratotype base. In the Ellesmere Island, this index species of the second zone coexists with *Hypophiceras gracile* (Spath) and *Vishnuites kummeli* Tozer. The *concavum* and *boreale* zones represent the lower Griesbachian.

In the stratotype area of the next *commune* Zone, *Ophiceras greenlandicum* Spath is found at the level of 53.3 m above the base of the Blind Fiord Formation. Other first occurrence levels are as follows: 54.2 m for *O. commune* Spath, 55.5 m for *O. sakuntala* Spath, 57.3 m for *Discophiceras wordiei* (Spath), and 65.2 m for *Wordieoceras wordiei* (Spath). In the Ellesmere Island, the ammonoid assemblage of the *commune* Zone includes as well *Tompophiceras extremum* (Spath). Ammonoids *Bukkenites macilentus* Tozer, *B. nitidus* Tozer, *B. strigatus* (Tozer), and *Wordieoceras wordiei* (Spath) appear within the interval of 65.5–150 m above the base of the Blind Fiord Formation in the stratotype area of the Griesbachian Stage. Their assemblage characterizes the *strigatus* Zone corresponding together with the *commune* Zone to the upper Griesbachian.

The northwestern area of the Ellesmere Island is the stratotype site of the Dienerian Stage spanning an upper part of the Confederation Point Member coupled with the basal portion of the Smith Creek Member. Basal in the stage is the *Proptychites candidus* Zone, stratotype of which is distinguished at the Diener River. This zone yields ammonoids of *Proptychites, Meekophiceras, Dunedinites, Pleurogyronites, Ambites, Pleurambites*, and *Prionolobus* genera.

The *Vavilovites sverdrupi* Zone having stratotype in bank cliffs of the Lindstroem River is terminal one in the Dienerian Stage. It includes the *Koninckites dimidiatus, Vavilovites obtusus*, and *Kingites discoidalis* subzones. The lower subzone that is distinguished in the Toad Formation of northeastern British Columbia yields only its index species *Koninckites dimidiatus* Tozer. Stratotypes of the *obtusus* Subzone overlying the *candidus* Zone is localized at the Diener River, where it yields *Vavilovites sverdrupi* (Tozer), *V. obtusus* Tozer, and *Wyomingites scapulatus* Tozer. *Xenodiscoides calnani* Tozer, *Prionolobus koninckii* Tozer, *Flemingites reticulates* Tozer, and *Tellerites* sp. presumably occur at the same level in northeastern British Columbia. The *discoidalis* subzone stratotype is located in the north of the Axel Heiberg Island, where it overlies the *obtusus* Subzone. Ammonoids characteristic of the *discoidalis* Subzone are *Kingites discoidalis* Tozer, *Heibergites heibergensis* (Tozer), and *Pseudosageceras multilobatum* Noetling.

The detailed ammonoid zonation of Lower Triassic in Siberia was elaborated in the period of 1970s–1990s (Dagys *et al.*, 1979; Dagys and Ermakova, 1988, 1990, 1993, 1996; Dagys, 1994, 1997).

The Induan Stage zonation was studied in sections of the eastern Verkhoyansk region (Vostochnaya Khandyga and Tompo river basins). The lower Induan is represented here by five ammonite zones of *Otoceras concavum, O. boreale, Tompophiceras pascoei, T. morphaeos*, and *Wordieoceras decipiens.*

Only index species *O. concavum* Tozer was found in the *concavum* Zone (12-m-thick sequence of shales with calcareous-clayey nodules), hypostratotype of

which is established at the Setorym River (Vostochnaya Khandyga riverhead area). In the same section, ammonoids of the next *boreale* Zone (39.3-m-thick shale beds with sandstone intercalations) are represented by *Otoceras boreale* Spath, *Aldanoceras tenue* Dagys et Ermakova, and presumably by *Episageceras antiquum* (Popow). The *pascoei* Zone (2.5-m-thick shale beds with interlayers of calcareous-clayey nodules) in the stratotype area at the Lekeer River (Tompo riverhead area) yields *Tompophiceras pascoei* (Spath) and *Hypophiceras gracile* (Spath). The *morphaeos* Zone of the same section (90.5-m-thick sequence of shales with calcareous-clayey nodules and interlayers) produced *Tompophiceras morphaeos* (Popow), *T. gerbaense* (Popow), *Aldanoceras tenue* Dagys et Ermakova, *Ophiceras transitorium* Spath, *Wordieoceras decipiens* (Spath), and *Metophiceras* aff. *subdemissum* Spath. The *decipiens* Zone of the Lekeer site (25-m-thick shale beds with scarce limy-clayey nodules) is characterized by association of *Wordieoceras decipiens* (Spath) and *W. tompoense* Dagys et Ermakova.

The upper Induan includes the *Vavilovites sverdrupi, V. turgidus*, and *Kingites korostelevi* zones. The middle one consists of *V. subtriangularis* and *V. umbonatus* subzones, and all the units are represented best of all in exposures of the Delin'ya River (Tompo River basin). The *sverdrupi* Zone (48- to 53-m-thick sequence of shales and siltstones with limy-clayey nodules) bears the sole ammonoid species *V. sverdrupi* (Tozer). The diverse *Vavilovites* species characterize the *turgidus* Zone. The *subtriangularis* Subzone of the latter (68-m-thick siltstone beds with calcareous-clayey nodules) hosts its index species *V. subtriangularis* Vavilov in association with first *V. turgidus* (Popow). In the *umbonatus* Subzone (52-m-thick siltstone beds with limy nodules), its guide form *V. umbonatus* Vavilov is found in association with *Vavilovites compressus* (Vavilov) and *V. turgidus* (Popow). The uppermost *korostelevi* Zone (20-m-thick siltstone beds with rare limy nodules) yields ammonoids *Sakhaitoides verchojanicus* (Popow), *S. allarensis* (Dagys et Ermakova), and *Episageceras antiquum* (Popow) in addition to the index species *Kingites korostelevi* (Zakharov).

CORRELATION

The Induan Stage includes two substages, the lower of which spans the *Otoceras* and *Ophiceras* beds. Investigations of the recent period showed that the *Otoceras* Beds, the basal ones in the Triassic System, are most representative not in the Tethyan region, where they have been originally distinguished, but in the Boreal areas. In these areas, the beds in question exhibit several correlative levels. The lowermost level of this kind is the *concavum* Zone reliably distinguished in the Axel Heiberg Island of Canada and in the eastern Verkhoyansk region of Siberia (table). The next *boreale* Zone of Canada can be correlated with the *boreale* and *pascoei* zones of Siberia, because they all bear *Otoceras boreale* and *Hypophiceras gracile.*

The Tethyan region appears to be lacking analogues of the *concavum* Zone. In most sections, the *Otoceras* Beds correspond here to the *woodwardi* Zone, the index species of which is however very similar in morphology to *O. boreale.* Judging from this similarity, Kummel (1972) considered the latter as a subspecies of *O. woodwardi.* Choosing close analogues of the Canadian *boreale* Zone in the Tethyan region, one must select the *latilobatum* and *woodwardi* zones in the Selong section of southern Tibet, where they yield their index species only (Wang *et al.*, 1988). In other Tethyan sections, the *woodwardi* Zone is characterized by a mixed ammonoid fauna consisting of *Otoceras* and *Ophiceras* species. In the Boreal region, such a fauna characterizes an upper part of the *boreale* Zone and basal *Ophiceras* Beds (lower intervals of the *commune* Zone in Canada and *morphaeos* Zone in Siberia).

In Central Himalayas, the *Ophiceras* Beds correspond to the *tibeticum* Zone already lacking otoceratids. This zone is correlative with the *tibeticum* and *Ophiceras* sp. zones of Kashmir, with the greater part of the synonymous zone in Nepal (the *ptychodes* Subzone included), and with the *connectens* Zone of the Salt Range. In Canada, the *tibeticum* Zone can be correlated with the upper Griesbachian, the basal interval excluded, because *Discophiceras* and *Bukkenites* are genera in common for both units. In turn, the *commune* and *strigatus* zones of Canada show similarity with the *morphaeos* and *decipiens* zones of Siberia, since *Ophiceras* and *Wordieoceras* forms appear exactly at these levels.

The upper Induan begins at the appearance level of meekoceratids, the first representatives of Triassic ceratites having flat venter. In the Salt Range stratotype area, the upper Induan spans intervals of the lower Ceratite Limestone (*frequens* Zone), Ceratite Marl (*rotundatus, fallax*, and *volutes* zones), and basal interval of the Ceratite sandstone (up to the first occurrence level of *Flemingites* forms).

Equivalents of the upper Induan are the *Meekoceras* Beds (*markhami* Zone) of central Himalayas, as well as the *Paranorites–Vishnuites* and *Prionites–"Koninckites"* (= *Radioceras*) zones of Kashmir. In Nepal, first meekoceratids (*Gyronites, Ambites, Zhaojinkeoceras*, and *Kymatites* forms) appear in the upper interval of the *tibeticum* Zone (Waterhouse, 1994). Consequently, the lower limit of the upper Induan is somewhere inside this zone, and the *frequens* Zone of Nepal corresponds to an upper part of the synonymous standard zone. The upper Induan boundary coincides in Nepal with the top of the *jomsomensis* Zone (see the table).

The Dienerian Stage of Canada is an equivalent of the upper Induan. Its lower boundary corresponds to the base of the *candidus* Zone that yields first meekoceratids (*Meekoceras, Pleurogyronites, Ambites*, and *Prionolobus* species). The overlying *sverdrupi* Zone, with

Ammonoid zonation of the Induan Stage

Central Himalayas			Kashmir			Nepal				Salt Range				Canada			Siberia	
Olenekian	*Hedenstroemia* Beds	*Flemingites (Rohillites) rohilla*	Khunamuh Formation	*H*	86–91	*Owenites–Kashmirites*	Gangapurnan	Nar		*Nordophiceras erbeni*	Mianwali Formation	Mittiwali	Ceratite Sandstone	*Flemingites* sp.	Smithian	*Euflemingites romunduri*	Olenekian	*Lepiskites kolymensis*
										Arctoceras chuluense						*Hedenstroemia hedenstroemi*		*Hedenstroemia hedenstroemi*
upper Induan	*Meekoceras* Beds	*Prionolubus markhami*		*G*	78–85	*Prionites–"Koninckites"*	Annapurnan	Khangsar	Kangla	*Pleurogyronites jomsomensis*				*Paranorites* sp.	Dienerian	*Vavilovites sverdrupi*	upper Induan	*Kingites korostelevi*
													Ceratite Marl	*Koninckites volutus*		*Kingites discoidalis*		
									Jargeng	*Kingites elegans*				*Shevyrevoceras fallax*				*Vavilovites turgidus*
										Proptychites abundans				*Prionolobus rotundatus*		*Vavilovites obtusus*		*Vavilovites sverdrupi*
				F	71–77	*Paranorites–Vishnuites*			Sabche	*Gyronites frequens*			Lower Ceratite Limestone	*Gyronites frequens*		*Koninckites dimidiatus*		
																Proptychites candidus		
lower Induan	*Otoceras–Ophiceras* beds	*Ophiceras tibeticum*		*E*	E_3 60–70	*Ophiceras* sp.	Gangetian	Pangjang	Chegadji	*Ophiceras tibeticum*		Kathwai	middle–upper	*Ophiceras connectens*	Griesbachian	upper		*Bukkenites strigatus*	lower Induan	*Wordieoceras decipiens*
						O. tibeticum				*Lytophiceras ptychodes*						*Ophiceras commune*		*Tompophiceras morphaeos*
		Otoceras woodwardi			E_2 52–59	*Otoceras woodwardi*			Pengba	*Metotoceras dieneri* *Otoceras woodwardi*						lower		*Otoceras boreale*		*Tompophiceras pascoei*
																		Otoceras boreale
																Otoceras concavum		*Otoceras concavum*

its *dimidiatus, obtusus*, and *discoidalis* subzones, is topmost in the Dienerian Stage.

The upper Induan of Siberia spans the *sverdrupi, turgidus*, and *korostelevi* zones. The former two can be easily correlated with the *obtusus* Zone of Canada, because the distribution ranges of *Vavilovites* forms correspond to these zones only. The *korostelevi* Zone of Siberia corresponds to the level of the Canadian *discoidalis* Zone, since they both overlie the *Vavilovites* beds and underlie the *hedenstroemi* Zone. If this is correct, then analogues of the Canadian *candidus* Zone and *dimidiatus* Subzone are missing from Siberian sections.

The upper Induan boundary is simultaneously the base of the Olenekian Stage, stratotype of which is established in lower courses of the eponymous river. The boundary in question coincides here with the base of the *hedenstroemi* Zone (see the table) that has been distinguished as well in the Verkhoyansk region, eastern Taimyr, Kolyma River basin, Kotel'nyi Island, and Arctic Canada. Paleontological remains are scanty in this zone. Everywhere, it yields only the index species *Hedenstroemia hedenstroemi* (Keys.), sometimes in association with *H. tscherskii* (Popow).

Outside Boreal areas, *Hedenstroemia* remains are almost unknown except for finds in southern Primor'e and in some areas of the United States. Accordingly, it is difficult to trace the lower Olenekian boundary in Tethyan sections. In order to shed some light on its position, we should briefly analyze composition of ammonoid assemblages from beds underlying and overlying the *hedenstroemi* Zone.

In Siberia, beds below that zone yield *Sakhaitoides, Kingites, Episageceras*, and diverse *Vavilovites* species (*korostelevi, turgidus*, and *sverdrupi* zone). Above it, there were found representatives of genera *Lepiskites, Kelteroceras, Melagathiceras, Clypeoceratoides, Meekoceras, Arctoceras, Euflemengites, Juvenites, Sakhaites, Hedenstroemia*, and *Anakashmirites* (*kolymensis* Zone).

Beds underlying the *hedenstroemi* Zone in Canada bear species of *Kingites, Heibergites, Wyomingites, Koninckites*, and *Vavilovites* genera (*sverdrupi* Zone). *Xenodiscoides, Prionolobus, Flemingites*, and *Tellerites* forms may occur at the same level. Ammonoids found above the zone belong to genera *Kashmirites, Melagathiceras, Juvenites, Thermalites, Gyronites, Prionolobus, Meekoceras, Euflemingites, Arctoceras*, and *Paranannites* (*romunduri* Zone).

In the western United States, the Olenekian Stage begins with the *gracilitatis* Zone that contains species of genera *Meekoceras, Flemingites, Euflemingites, Arctoceras, Juvenites, Thermalites, Kashmirites, Xenoceltites, Owenites, Inyoites, Parussuria, Pseudohedenstroemia, Anahedenstroemia*, possibly accompanied by representatives of *Hedenstroemia, Lanceolites, Aspenites*, and some other genera. The ammonoid assemblage of this zone enables its correlation either with the *hedenstroemi* and *romunduri* zone of Canada, and with the *hedenstroemi* and *kolymensis* zones of Siberia, or with the upper zones of both pairs.

In the Salt Range, the lower Olenekian boundary is somewhere inside the Ceratite Sandstone, the lower part of which bears species of genera *Pseudoceltites, Kymatites, Pleurogyronites, Paranorites, Gyrophiceras, Preflorianites, Xenodiscoides, Koninckites, Khangsaria*, and *Radioceras*. The middle and upper parts of this unit hosts ammonoids of genera *Flemingites, Rohillites, Clypeoceras, Pseudoflemingites, Paraspidites, Prionites, Xenoceltites, Pseudoceltites, Kashmirites, Anakashmirites, Xenodiscoides, Preflorianites, Anahedenstroemia, Paranorites, Beoflemingites, Eoptychites, Fuchsites, Koninckites, Waagenoptychites*, and others. Presence of *Flemingites, Anahedenstroemia*, and *Pseudohedenstroemia* forms in the middle and upper intervals of the Ceratite Sandstone suggests that the corresponding *flemingianus* Zone can be correlated with the *gracilitatis* Zone of the United States, and via the latter, with the *hedenstroemi* and *romunduri* zones of Canada, or with the *hedenstroemi* and *kolymensis* zones of Siberia (see the table).

In Nepal, the lower Olenekian boundary is traceable between the *jomsomensis* and *chuluense* zones. Typical Induan genera *Gyrophiceras, Gyronites, Pleurogyronites, Gyrolecanites, Lilangia, Radioceras, Khangsaria, Proptychites*, and *Clypites* are characteristic of the former zone. The *Arctoceras* genus typical of the basal Olenekian Stage appears in the next *chuluense* Zone.

In Kashmir, the lower Olenekian boundary corresponds to the base of the *Owenites–Kashmirites* Zone. In Central Himalayas, it is detected at the base of the *rohilla* Zone, where the ammonoid assemblage is similar (and presumably coeval) to that of the *flemingianus* Zone of the Salt Range.

In southern Primor'e, the Olenekian Stage begins with the local *Hedenstroemia bosphorensis* Zone. In the Russkii Island and western coast of the Ussuriiskii Bay, this zone yields diverse species of genera *Arctoceras, Meekoceras, Hedenstroemia, Flemingites, Euflemingites, Owenites, Dieneroceras*, and others (Zakharov, 1994, 1997). On the basis of their assemblage, the zone can be correlated with the *gracilitatis* Zone of United States and with the *flemingianus* Zone of the Salt Range.

CONCLUSION

(1) The *Otoceras* Beds represent basal unit of the Induan Stage. In the Boreal region, where the beds are recognizable better than in other regions, they span interval of the *concavum* and *boreale* ammonoid zones below the *Ophiceras* Beds. In the Tethyan region, the *Otoceras* Beds correspond to the *woodwardi* Zone correlative in most sections with an upper part of the *boreale* Zone coupled with basal *Ophiceras* Beds of Boreal sections. Accordingly, the base of the Triassic is diachronous worldwide.

(2) In its stratotype area, the upper Induan Substage begins at the first occurrence level of meekoceratids, the first representatives of Triassic ceratites having flat venter. This boundary is well traceable in both the Tethyan and Boreal regions.

(3) The upper Induan boundary that coincides with the base of the Olenekian Stage is distinct in Boreal areas, where it corresponds to the base of the *hedenstroemi* Zone. Its position in Tethyan sections is less distinct and can be tentatively placed at the base of the *flemingianus* Zone and its analogues.

Reviewers V.A. Zakharov and A.G. Konstantinov

REFERENCES

Ali, S.T., Shuja, T.A., Qureshi, K.A., *et al.*, Permian and Triassic Systems in the Salt Range and Surghar Range, Pakistan, *The Tethys: Her Paleogeography and Paleobiogeography from Paleozoic to Mesozoic*, Tokyo: Tokai Univ. Press, 1985, pp. 221–312.

Bando, Y., Lower Triassic Ammonoids from Guruyl Ravine and the Spur Three Kilometers North of Burus, *Palaeontol. Indica. New Ser.*, 1981, vol. 46, pp. 135–177.

Bhatt, D.K. and Arora, R.K., Otoceras Bed of Himalaya and Permian-Triassic Boundary: Assessment and Elucidation with Conodont Data, *J. Geol. Soc. India*, 1984, vol. 25, no. 11, pp. 720–727.

Bhatt, D.K. and Joshi, V.K., A Note on the Occurrence of Glyptophiceras Spath from Spiti, with Preliminary Observations on the Fauna of Otoceras-Ophiceras Beds, *Rec. Geol. Surv.*, 1981, vol. 112, Pt. 8, pp. 51–54.

Dagys, A.S., Zonal Scheme of the Boreal Lower Triassic and the Boundary between Induan and Olenekian Stages, *Tikhookean. Geol.*, 1997, vol. 16, no. 4, pp. 36–40.

Dagys, A.S. and Ermakova, S.P., *Boreal'nye pozdneolenekskie ammonoidei* (Late Olenekian Boreal Ammonoidea), Moscow: Nauka, 1988.

Dagys, A.S. and Ermakova, S.P., *Ranneolenekskie ammonoidei Sibiri* (Early Olenekian Ammonoidea of Siberia), Moscow: Nauka, 1990.

Dagys, A.S. and Ermakova, S.P., Scheme of Detailed Biostratigraphy of the Boreal Lower Triassic, *Stratigr. Geol. Korrelyatsiya*, 1993, vol. 1, no. 2, pp. 26–36.

Dagys, A.S., Arkhipov, Yu.V., and Bychkov, Yu.M., *Stratigrafiya triasovoi sistemy Severo-Vostoka Azii* (Stratigraphy of Triassic System of Northeastern Asia), Moscow: Nauka, 1979.

Dagys, A.S. and Ermakova, S., Induan (Triassic) Ammonoids from Northeastern Asia, *Rev. Paleobiol.*, 1996, vol. 15, no. 2, pp. 401–447.

Dagys, A.S., Lower Triassic Stage, Substage and Zonal Scheme of North-Eastern Asia, *Mem. Geol. Lausanne*, 1994, no. 22, pp. 15–23.

Diener, C., The Cephalopoda of the Lower Trias, *Palaeontol. Indica. Ser. 15*, 1897, vol. 2, part 1, pp. 1–181.

Diener, C., The Trias of the Himalayas, *Mem. Geol. Surv. India*, 1912, vol. 36, part 3, pp. 1–159.

Embry, A.F., Stratigraphic Subdivision of the Blind Fiord and Bjorne Formations (Lower Triassic), Sverdrup Basin, Arctic Islands, *Pap. Geol. Surv. Canada*, 1986, no. 86-1B/1, pp. 329–340.

Griesbach, C.L., Palaeontological Notes on the Lower Trias of the Himalayas, *Rec. Geol. Surv. India*, 1880, vol. 13, part 2, pp. 83–113.

Guex, J., Le Trias Inférieur des Salt Ranges (Pakistan): Problèmes biochronologiques, *Eclog. Geol. Helv.*, 1978, vol. 71, no. 1, pp. 105–141.

Kapoor, H.M., Permo-Triassic Boundary of the Indian Subcontinent and Its Intercontinental Correlation, *Permo-Triassic Events in the Eastern Tethys: Stratigraphy, Classification and Relation with the Western Tethys*, New York: Cambridge Univ. Press, 1992, pp. 21–36.

Kapoor, H.M., The Guryul Ravine Section, Candidate of the Global Stratotype Section and Point of the Permo-Triassic Boundary, *Palaeozoic-Mesozoic Boundary: Candidates of the Global Stratotype Section and Point of the Permian-Triassic Boundary. Wuhan*, China Univ. Geosci. Press, 1996, pp. 99–110.

Kiparisova, L.D. and Popov, Yu.N., Subdivision of the Lower Series of the Triassic System into Stages, *Dokl. Akad. Nauk SSSR*, 1956, vol. 109, no. 4, pp. 842–845.

Kiparisova, L.D. and Popov, Yu.N., Project of Subdivision of the Triassic Lower Series into Stages, *Stratigrafiya verkhnego paleozoya i mezozoya yuzhnykh biogeograficheskikh provintsii* (Stratigraphy of the Upper Paleozoic and Mesozoic in Southern Biogeographic Provinces, Reports of Soviet Geologists to 22nd Session of International Geological Congress, Problem 16a), Moscow: Nedra, 1964, pp. 91–99.

Kozur, H.W., Some Aspects of the Permian-Triassic Boundary (PTB) and of the Possible Causes for the Biotic Crisis around This Boundary, *Palaeogeogr., Palaeoclimatol., Palaeoecol.*, 1998, vol. 143, no. 4, pp. 227–272.

Krafft, A. and Diener, C., Lower Triassic Cephalopoda from Spiti, Malla Johar, and Byans, *Palaeontol. Indica. Ser. 15*, 1909, vol. 6, no. 1, pp. 1–186.

Krystyn, L. and Orchard, M.J., Lowermost Triassic Ammonoid and Conodont Biostratigraphy of Spiti, India, *Albertiana*, 1995, no. 17, pp. 10–21.

Kummel, B., Ammonoids from the Kathwai Member, Mianwali Formation, Salt Range, West Pakistan, *Stratigraphic Boundary Problems: Permian and Triassic of West Pakistan. Lawrence*, Univ. Kansas Press, 1970, pp. 177–192.

Kummel, B., The Lower Triassic (Scythian) Ammonoid Otoceras, *Bull. Mus. Compar. Zool. Harvard Univ.*, 1972, vol. 143, no. 6, pp. 365–418.

Kummel, B. and Steele, G., Ammonites from the Meekoceras Gracilitatus Zone at Crittenden Spring, Elko County, Nevada, *J. Paleontol.*, 1962, vol. 36, no. 4, pp. 638–703.

Kummel, B. and Teichert, C., Relations between the Permian and Triassic Formations in the Salt Range and Trans-Indus Ranges, West Pakistan, *Neues Jab. Geol. Palaontol. Abh.*, 1966, vol. 125, pp. 297–333.

Kummel, B. and Teichert, C., Stratigraphy and Paleontology of the Permian–Triassic Boundary Beds, Salt Range and Trans-Indus Ranges, West Pakistan, *Stratigraphic Boundary Problems: Permian and Triassic of West Pakistan. Lawrence*, Kansas Univ. Press, 1970, pp. 1–110.

Mojsisovics, E., Waagen, W., and Diener, C., Entwurf einer Gliederung der pelagischen Sedimente des Trias-Systems, *Sitzungsber. Akad. Wiss. Wien. Math.-Naturwiss. Kl.*, 1895, vol. 104, Abt. 1, pp. 1–32.

Nakazawa, K., Analysis of Late Permian and Early Triassic Faunas of Kashmir, *Mem. Geol. Surv. India*, 1981, vol. 46, pp. 191–204.

Nakazawa, K., Stratigraphy of the Permian–Triassic Transition and the Paleozoic–Mesozoic Boundary, *Bull. Geol. Surv. Japan*, 1993, vol. 44, no. 7, pp. 425–445.

Nakazawa, K., Kapoor, H.M., Ishii, K., *et al.*, The Upper Permian and the Lower Triassic in Kashmir, India, *Mem. Fac. Sci. Kyoto Univ. Ser. Geol. Mineral.*, 1975, vol. 42, no. 1, pp. 1–106.

Nakazawa, K. and Kapoor, H.M., The Upper Permian and Lower Triassic Faunas of Kashmir, *Palaeontol. Indica. New Ser.*, 1981, vol. 46, pp. 1–204.

Noetling, F., Die asiatische Trias, *Lethaea Geognostica. T. 2. Das Mesozoicum. Bd. 1. Trias. Lief. 2. Stuttgart*, Schweizerbart, 1905, pp. 107–221.

Pakistani-Japanese Research Group. Permian and Triassic Systems in the Salt Range and Surghar Range, Pakistan, *The Tethys: Her Paleogeography and Paleobiogeography From Paleozoic to Mesozoic*, Tokyo: Tokai Univ. Press, 1985, pp. 221–312.

Shevyrev, A.A., The Lower Boundary of the Triassic and Its Correlation in Marine Sediments: Article 1. Boundary Sections of the Tethys, *Stratigr. Geol. Korrelyatsiya*, 1999a, vol. 7, no. 2, pp. 14–27.

Shevyrev, A.A., Ammonite Zones of Induan Stage (Lower Triassic) and Their Correlations, *Iskopaemye tsefalopody: Noveishie dostizheniya v ikh izuchenii* (Fossil Cephalopods: Last Achievements in Their Study), Moscow: Paleontol. Inst. Ross. Akad. Nauk, 1999b, pp. 289–304.

Shevyrev, A.A., The Lower Boundary of the Triassic and Its Correlation in Marine Sediments: Article 2. Boreal Section with the Permian–Triassic Boundary Deposits of the Tethys, *Stratigr. Geol. Korrelyatsiya*, 2000, vol. 8, no. 1, pp. 55–65.

Shevyrev, A.A. and Lozovskii, V.R., The Permian–Triassic Boundary in Marine Boundary, *Granitsa permi i triasa v kontinental'nykh seriyakh Vostochnoi Evropy* (The Permian–Triassic Boundary in Continental Sequences of Eastern Europe), Moscow: GEOS, 1998, pp. 184–209.

Tozer, E.T., Lower Triassic Stages and Ammonoid Zones of Arctic Canada, *Pap. Geol. Surv. Canada*, 1965, no. 65-12, pp. 1–14.

Tozer, E.T., A Standard for Triassic Time, *Bull. Geol. Surv. Canada*, 1967, no. 156, pp. 1–103.

Tozer, E.T., Canadian Triassic Ammonoid Faunas, *Bull. Geol. Surv. Canada*, 1994, no. 467, pp. 1–663.

Vosscher, H., The New STS Triassic Stage Nomenclature, *Albertiana*, 1992, no. 10, p. 1.

Waagen, W., Salt Range Fossils. 2. Fossils From the Ceratite Formation, *Palaeontol. Indica. Ser. 13*, 1895, vol. 2, pp. 1–323.

Wang, Y., Chen, Ch., and Rui, L., A Potential Global Stratotype of the Permian-Triassic Boundary, *Permophiles*, 1988, no. 13, pp. 3–7.

Waterhouse, J.B., The Early and Middle Triassic Ammonoid Succession of the Himalayas in Western and Central Nepal. Pt. 1. Stratigraphy, Classification and Early Scythian Ammonoid Systematics, *Palaeontographica. Abt. A*, 1994, vol. 232, Lfg. 1–3, pp. 1–83.

Waterhouse, J.B., The Early and Middle Triassic Ammonoid Succession of the Himalayas in Western and Central Nepal. Part 2. Systematic Studies of the Early Middle Scythian, *Palaeontographica. Abt. A*, 1994, vol. 241, Lfg. 1–3, pp. 27–100.

Waterhouse, J.B., The Early and Middle Triassic Ammonoid Succession of the Himalayas in the Western and Central Nepal. Part. 3, Late Middle Scythian Ammonoids, *Palaeontographica. Abt. A*, 1996B, vol. 241, Lfg. 4–6, pp. 101–167.

Yin, H. and Tong, J., Multidisciplinary High-Resolution Correlation of the Permian-Triassic Boundary, *Palaeogeogr., Palaeoclimatol., Palaeoecol.*, 1998, vol. 143, no. 4, pp. 199–212.

Zakharov, Yu.D., Stratotype of the Boundary between Induan and Olenekian Stages of the lower Triassic, *Tikhookean. Geol.*, 1994, vol. 13, no. 4, pp. 33–44.

Zakharov, Yu.D., Ammonoid Evolution and the Problem of the Stage and Substage Division of the Lower Triassic, *Mém. Geol. Lausanne*, 1997, no. 30, pp. 121–136.

Zhamoida, A.I., Romanovskaya, G.M., and Rostovtsev, K.O., Common Stratigraphic Scale of the Triassic System, *Postanovleniya Mezhved. stratigr. kom-ta i ego postoyannykh komissii* (Resolution of Interdepartmental Stratigraphic Commitee and Its Continuous Commissions), Leningrad: Vses. Geol. Inst., 1982, no. 20, pp. 35–37.

Stratigraphy and Geological Correlation, Vol. 9, No. 5, 2001, pp. 483–490. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 9, No. 5, 2001, pp. 69–76.
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The Middle–Upper Oxfordian Boundary in the East European Platform

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Abstract—The position of the middle–upper Oxfordian boundary in the East European platform (Boreal region) and in the Subboreal and Submediterranean biogeographic provinces is discussed. In order to ensure the boundary isochronism in the Boreal belt, it should be placed between the *Amoeboceras alternoides* and *Amoeboceras ilovaiskii* subzones. This proposal means a return to the unified stratigraphic scheme of Mesozoic sediments of 1962. In addition, characteristics of the middle Oxfordian Rat'kovo Formation that is first distinguished in the Upper Jurassic succession of the Moscow syneclise are presented.

Key words: Jurassic, Oxfordian, substage, zone, correlation, Podmoskovnaya and Rat'kovo formations, Vykhino Horizon.

The study of last decades on the Oxfordian sediments in the East European (Russian) platform was closely related with the name of M.S. Mesezhnikov. He organized the Interdepartmental regional stratigraphic conference (IRSC) on the Jurassic of the Russian platform and put much effort and energy in its preparation. The conference was held in 1988.

The ammonite and foraminifer zonations, which are accepted in the Unified stratigraphic scheme of the Jurassic sediments of the Russian platform (*Unifitsirovannaya stratigraficheskaya...*, 1989) were elaborated for the IRSC and published in two papers: "Jurassic zones in the USSR" edited by Krymgol'ts (*Zony Yurskoi sistemy...*, 1982), and "Biostratigraphy of the Upper Jurassic sediments according to foraminifers" edited by Grigelis (1982). The stratigraphic scheme for the Oxfordian–Volgian interval of the Upper Jurassic was worked out by Mesezhnikov. A project of the regional scale for the Russian platform, where local stratigraphic units were correlated at the zonal level with that scheme, was developed in 1985. The correlation of Oxfordian deposits in the Moscow syneclise corresponded to that shown in Table 1.

The Podmoskovnaya Formation was quite rightfully assigned to the full range of the middle Oxfordian, because the summary interval of the *Cardioceras vertebrale* and *Amoeboceras alternoides* zonules roughly corresponded to the *Martelliceras martelli–Cardioceras zenaidae* Zone of the Unified stratigraphic scheme of the Mesozoic of the Russian platform (*Reshenie Vsesoyuznogo...*, 1962) or to the *Cardioceras zenaidae* Zone distinguished by Gerasimov (1971) in the Moscow syneclise. *Cardioceras zenaidae* Ilov., *C. rotundatum* Nik., *Amoeboceras ilovaiskii* (Sok.) and *A. alternoides* (Nik.) were recognized as most characteristic ammonite species of the latter zone. Precisely these ammonites are common to the Podmoskovnaya Formation, which also yields foraminifers of the *Ophthalmidium strumosum* Zone, which occur throughout its whole range.

The project of the regional scale of the Russian platform adopted on at the extended meeting of the bureau of the constant ISC Commission on the Jurassic (January 31, 1985), was significantly changed during three years before consideration at the IRSC. The changes were initiated by Mesezhnikov. Based on a detailed study of ammonite distribution in the Makar'ev reference section of the Oxfordian in the Kostroma region (Mesezhnikov *et al.*, 1986), he proposed the middle–upper Oxfordian zonation close to that developed by Sykes and Callomon (1979) in Scotland. Two years later this version of the regional scale with partly modified distinction of the middle Oxfordian subzones was published in the paper "The Jurassic ammonite zones of the USSR" included in a special collection of articles of the Geological Society of America (*The Jurassic Ammonite...*, 1988). This version corresponds to that shown in Table 2.

The Oxfordian zonation suggested in such a form for the Russian platform was included in the Unified stratigraphic scheme and correlated with the general scale. A serious error was committed therewith. In their stratigraphic scheme for the Boreal Upper Jurassic, Sykes and Callomon who, like Mesezhnikov, were proponents of the middle–upper Oxfordian boundary position at the first occurrence level of *Amoeboceras* forms considered this level as diachronous in the biogeographic province under consideration (the Skye Island in northwestern Scotland) and in the Subboreal belt, where the Oxfordian stratotype is situated (southern

Table 1. Scheme of the Oxfordian stratigraphic subdivision in the Moscow syneclise (project of 1985)

General scale			Regional scheme of the Russian platform		Local stratigraphic units of the Moscow syneclise
Stage	Substage	Zone	Ammonite zonule	Foraminifer zonule	
Oxfordian	upper	*Ringsteadia pseudocordata*	*Amoeboceras novoselkense*	*Epistomina uhligi-Lenticulina russiensis*	Ermolino Formation (part)
		Decipia decipiens	*Amoeboceras alternans*		
		Perisphinctes cautisnigrae			Kolomenskoe sequence
	middle	*Gregoryceras transversarium*	*Amoeboceras alternoides*	*Ophthalmidium strumosum*	Podmoskovnaya Formation
		Perisphinctes plicatilis			
			Cardioceras vertebrale		
	lower	*Cardioceras cordatum*	*Cardioceras cordatum*	*Ophthalmidium sagittum – Epistomina volgensis*	Podosinki Formation (part)
		Quenstedtoceras mariae	*Quenstedtoceras mariae*		

Table 2. Middle–upper Oxfordian ammonite zonation in the Boreal region

Substage	Mesezhnikov (Russian platform)		Sykes and Callomon (1979), Scotland	
	Zone	Subzone	Zone	Subzone
upper	*Amoeboceras ravni*		*Amoeboceras rozenkrantzi*	*Amoeboceras bauhini*
				Amoeboceras marstonense
			Amoeboceras regulare	
	Amoeboceras serratum	*Amoeboceras serratum*	*Amoeboceras serratum*	*Amoeboceras serratum*
		Amoeboceras koldeweyensis		*Amoeboceras koldeweyensis*
	Amoeboceras alternoides	*Amoeboceras alternoides*	*Amoeboceras glosense*	*Amoeboceras glosense*
		Amoeboceras ilovaiskii		*Amoeboceras ilovaiskii*
middle	*Cardioceras tenuiserratum*	*Cardioceras* (*Miticardioceras*) spp.	*Cardioceras tenuiserratum*	*Cardioceras blakei*
		Cardioceras zenaidae		*Cardioceras tenuiserratum*
	Cardioceras densiplicatum	*Cardioceras densiplicatum*	*Cardioceras densiplicatum*	*Cardioceras maltonense*
		Cardioceras popilaniense		*Cardioceras vertebrale*

England). When Mesezhnikov automatically placed the middle–upper Oxfordian boundary of the general scale at the level that separates *Cardioceras tenuiserratum* and *Amoeboceras alternoides* zones in the Boreal region, the Podmoskovnaya Formation became correlated not only with the middle Oxfordian, but also with the *Amoeboceras ilovaiskii* Subzone of the upper Oxfordian.

The unjustified decision of Mesezhnikov to consider the first occurrence level of *Amoeboceras* form in the Boreal belt as corresponding to the middle–upper Oxfordian boundary of the general scale was commented by Olfer'ev in the Explanatory note to the unified scheme (*Unifitsirovannaya stratigraficheskaya...*, 1993). According to Sykes and Callomon (1979), species *Amoeboceras ilovaiskii* (Sok.) was encountered in beds underlying the *Amoeboceras nunningtonense* Subzone of the Boreal Oxfordian reference section in the Skye Island. The latter unit corresponds to the uppermost *Perisphinctes pumilis* Zone that is identical in age to the standard *Gregoryceras transversarium* Zone of the middle Oxfordian. Accordingly, the *Amoeboceras ilovaiskii* Subzone, where representatives of this genus first appear in the Russian platform, cannot

Table 3. Correlation of the middle and lower upper Oxfordian in the Submediterranean, Subboreal, and Boreal regions (after Mesezhnikov,1989; with additions)

Submediterranean region			Subboreal region			Boreal region		
Substage	Zone	Subzone	Substage	Zone	Subzone	Substage	Zone	Subzone
upper	*Perisphinctes bifurcatus*		upper	*Perisphinctes cautisnigrae*	*Perisphinctes cautisnigrae*	upper (after Mesezhnikov)	*Amoeboceras serratum*	*Amoeboceras koldeweyense*
middle	*Gregoryceras transversarium*	*Larchellia schilli*	middle	*Perisphinctes pumilis*	*Amoeboceras nunningtonense*		*Amoeboceras alternoides*	*Amoeboceras alternoides*
		Perisphinctes parandieri			*Perisphinctes parandieri*			*Amoeboceras ilovaiskii*
	Perisphinctes plicatilis	*Perisphinctes antecendens*		*Perisphinctes plicatilis*	*Perisphinctes antecendens*	middle	*Cardioceras tenuiserratum*	*Cardioceras (Miticardioceras)* spp.
								Cardioceras zenaidae
							Cardioceras densiplicatum	*Cardioceras densiplicatum*
		Cardioceras vertebrale			*Cardioceras vertebrale*			*Cardioceras popilaniense*
lower	*Cardioceras cordatum*		lower	*Cardioceras cordatum*	*Cardioceras cordatum*	lower	*Cardioceras cordatum*	*Cardioceras cordatum*

be referred to the upper Oxfordian. The latter should begin either with the *Amoeboceras alternoides* Subzone, if we consider it as an analogue of the *Amoeboceras glosense* Subzone Scotland, like Mesezhnikov did, or with the *Amoeboceras serratum* Zone. Hantzpergue *et al.* (1998) argued for the former viewpoint and correlated the middle–upper Oxfordian boundary with that between the *Amoeboceras ilovaiskii* and *A. glosense* subzones. Gerasimov (1992) preferred the latter viewpoint and referred the *Amoeboceras ilovaiskii* and *A. alternoides* subzones to the middle Oxfordian.

Mesezhnikov himself apparently realized the incorrectness of the adopted correlation scheme, because in a monograph (Mesezhnikov *et al.*, 1989), published a month before his untimely death, there was presented a more valid correlation of the middle and lower upper Oxfordian in the Submediterranean, Subboreal, and Boreal regions, which is shown with some additions in Table 3.

The table shows that the "upper–middle" Oxfordian boundary coincides, in terms of Mesezhnikov, with that separating the *Gregoryceras transversarium* and *Perisphinctes plicatilis* zones in the Submediterranean province, and precisely these zones define the range of the middle Oxfordian according to both the International scale and the Jurassic stratigraphic scheme of the Russian platform adopted by the IRSC (*Unifitsirovannaya stratigraficheskaya...*, 1993).

When analyzing the "middle" Oxfordian zonation proposed by Mesezhnikov, we should acknowledge a great contribution of the paleontological group he headed to both the refinement and detailing of the Boreal Oxfordian stratigraphic scheme and to elucidation of distribution patterns of characteristic ammonites in the corresponding interval of the Jurassic in the Russian platform. This concerns especially the thin- and thick-ribbed Oxfordian cardioceratids *Cardioceras tenuicostatum* (Nik.) and *C. tenuistriatum* Boriss. widespread in the of the Russian platform. Previously, they were believed to be species of the *Cardioceras cordatum* Zone of the lower Oxfordian. Mesezhnikov and his colleagues recognized that these forms show in fact their first occurrence only in the middle Oxfordian *Cardioceras densiplicatum* Zone. After the work of 1989, the boundary position between the lower and middle Oxfordian in the Russian platform and range of the latter substage, except for the middle–upper Oxfordian border interval, were clearly defined. The aforementioned monograph also includes data on distribution of foraminifers studied by Azbel'. She established that the level of transition from the "lower Oxfordian" *Ophthalmidium sagittum–Epistomina volgensis* assemblage to the "middle Oxfordian" *Ophthalmidium strumosum–Lenticulina brestica* assemblage does not coincide with boundary between substages and corresponds to the boundary between *Cardioceras densiplicatum* and *Cardioceras tenuiserratum* zones of the middle Oxfordian. This point substantial to the Oxfordian subdivision by foraminifers introduced during the preparation of materials for publication was not included in the Jurassic regional stratigraphic scheme of the Russian platform by its approval in 1989. When the regional part of the scheme was corrected at the same time, the

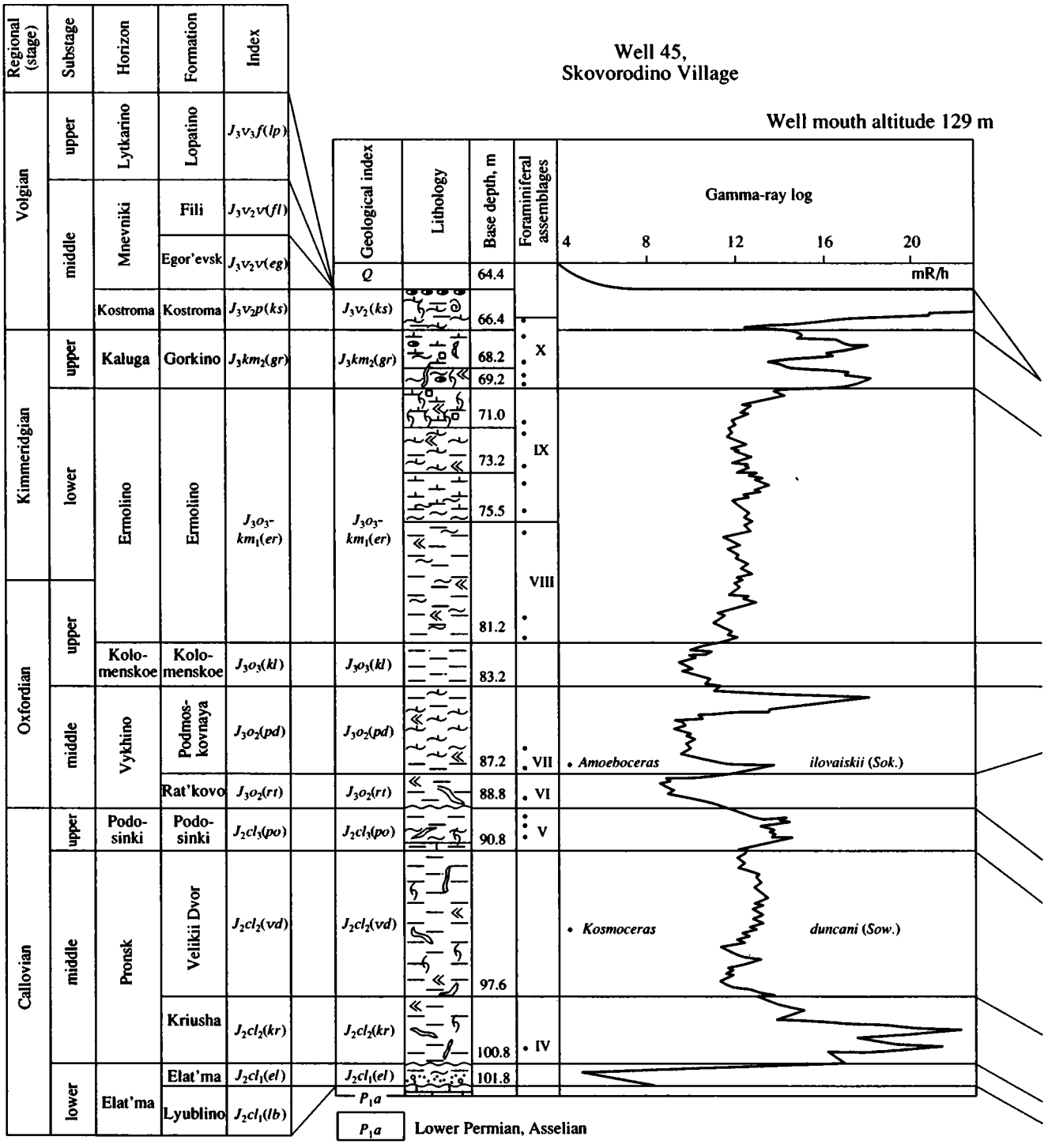


Figure.

boundary position between the Podmoskovnaya and Podosinki formations, which yield distinct microfaunas, was changed. As a result, the stratigraphic range of the Podosinki Formation that corresponded to the upper Callovian and lower Oxfordian, according resolutions of the IRSC on the Jurassic and Lower Cretaceous (February 29, 1988), was extended owing to incorporation of the middle Oxfordian *Cardioceras densiplicatum* Zone into this interval.

Recent research data showed the extended range of the Podosinki Formation range to be invalid, because the Oxfordian part of the section corresponding to the

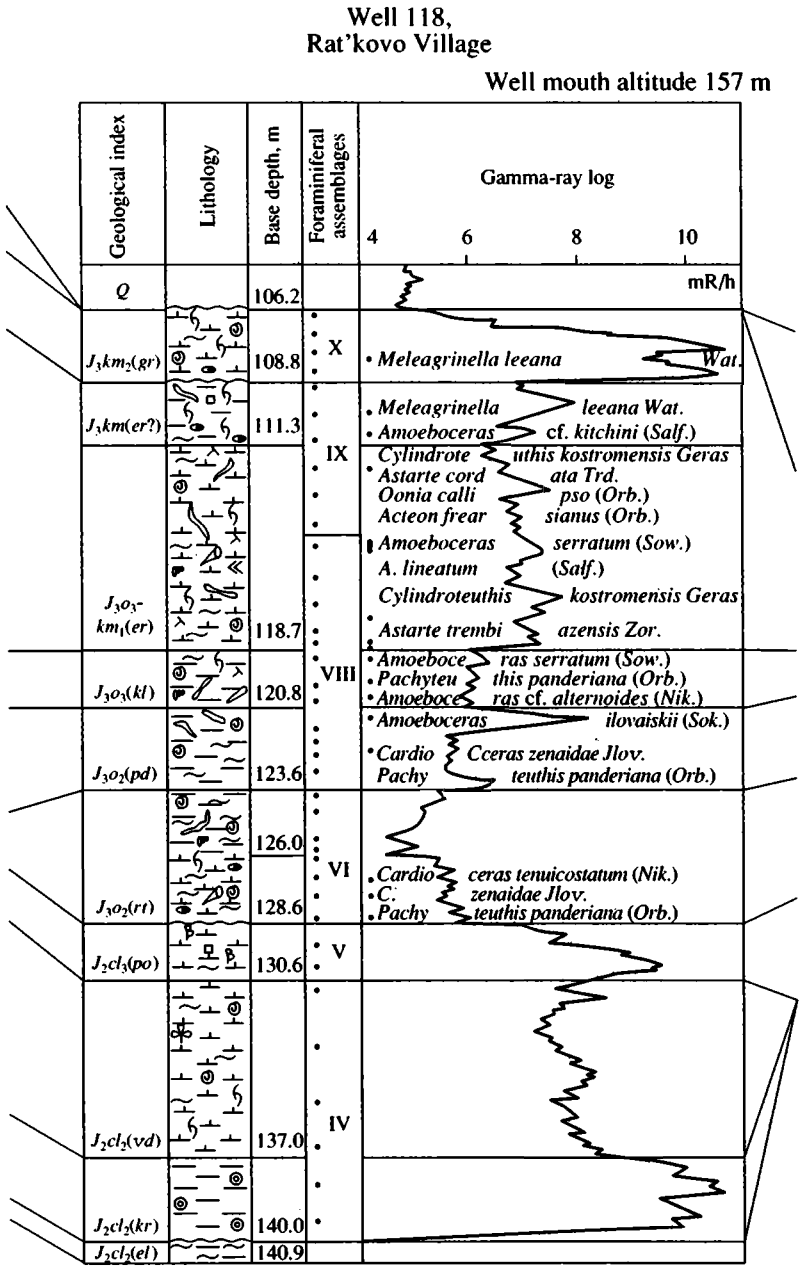


Figure. (Contd.)

Cardioceras densiplicatum Zone differs noticeably from the fine, perfectly elutriated Podosinki clays. That part is composed of gray to light gray silty, slightly micaceous, intensely bioturbated clays, outwardly resembling the upper Oxfordian Kolomenskoe sequence. Clays often yield finely splintered shelly detritus, abundant imprints and pyritized casts of small thin-ribbed ammonites, and pyritized plant remains. Fractures in the rocks are filled with pyrite partly or completely oxidized. In complete sections, their upper boundary with the Podmoskovnaya Formation is placed at the base of the platy, bituminous or bituminized clay bed and is distinctly recorded at gamma-ray log diagrams by its anomalously low activity. This part of the section is distinguished as the *Rat'kovo Formation* after the eponymous village in the Sergiev Posad district of the Moscow region, where its rocks have been recovered from the depth interval of 123.6–128.6 m of Well 118. This interval is chosen as the formation stratotype. The figure shows correlation of the complete Jurassic section, the Rat'kovo Formation included, with the gamma-ray logging data and paleontological records. Wells 45 (Skovorodino) and 118 (Rat'kovo) were drilled in the north of the Sergiev Posad district; wells 076 (Veshnyaki) and 077 (Vykhino), in the eastern margin of Moscow. Foramin-

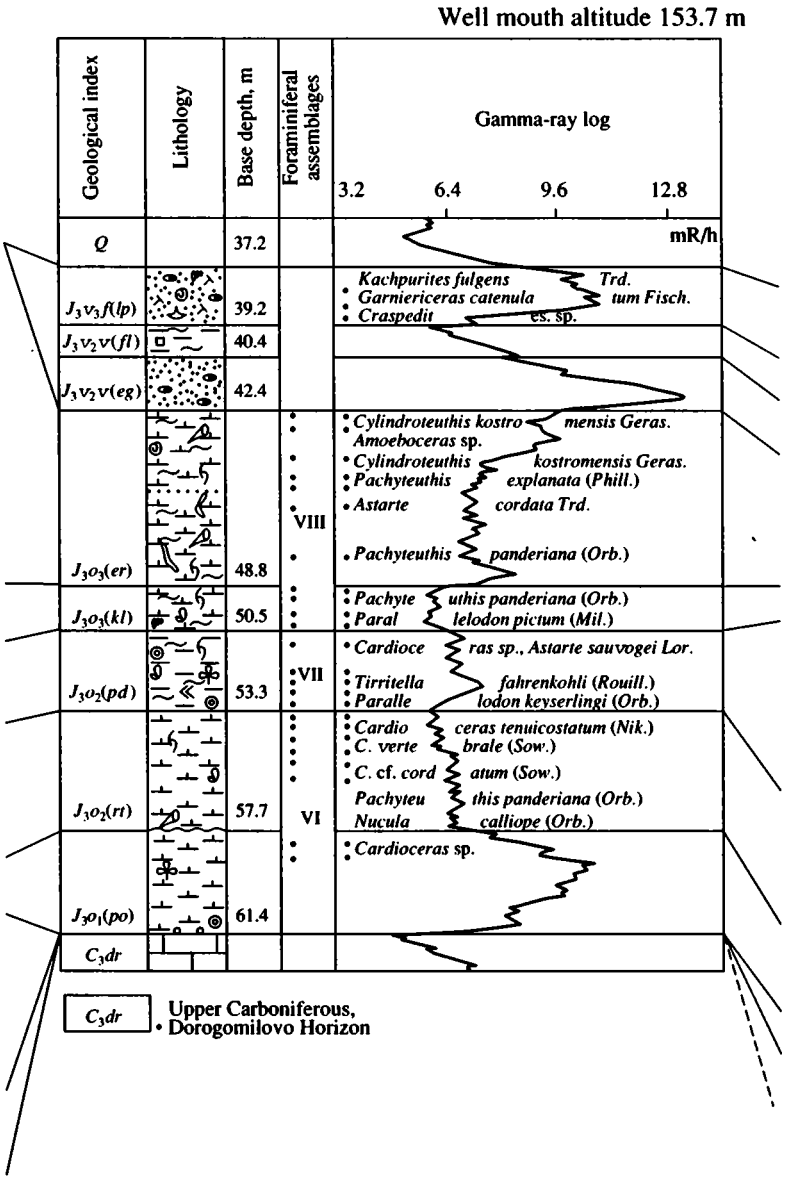


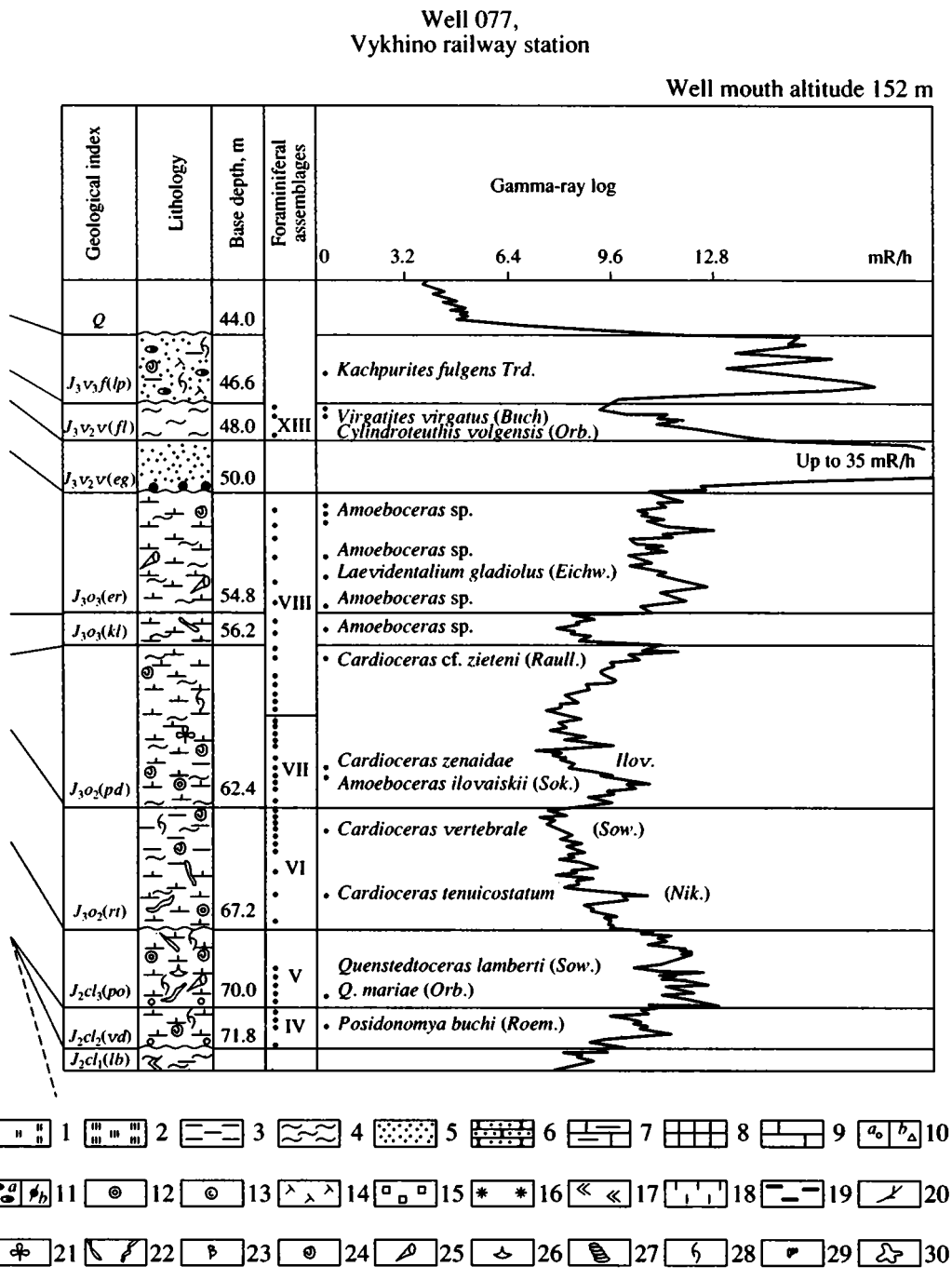
Figure. (Contd.)

ifers were identified by Azbel' and Osipova; mollusks, by Gerasimov.

Bed 2 that was described by Gerasimov (1996) in the well-known, but nonexistent nowadays, section of the Kamushki quarry in Moscow, is referred to the Rat'kovo Formation. The formation validity was approved at the extended meeting of the bureau of the Jurassic and Cretaceous section of the Interdepartmental Regional Stratigraphic Commission (IRSC) on the central and southern Russian platform on January 19, 1998, and approved by the IRSC bureau.

The Rat'kovo and Podmoskovnaya formations should be integrated into the Vykhino Horizon that approximately (in our opinion, exactly) corresponds to the middle Oxfordian. The eponymous site is the Vykhino railway station, near which the depth interval of 56.2–67.0 m of Well 077 is accepted for the type section of deposits under consideration. The correlation of the horizon and both formations with the regional scale is shown in Table 4.

When the Vykhino Horizon was distinguished, the extended meeting of the Jurassic and Cretaceous section bureau (January 19, 1998) decided to limit the range of the Podosinki Horizon by the joint interval of the upper Callovian and lower Oxfordian. The Podmoskovnyi Horizon was abolished at the same time.



Position of the Rat'kovo and Podmoskovnaya formations of the Vykhino Horizon in the Jurassic sequence: (1) tripoli; (2) opoka; (3) clay; (4) silt; (5) sand; (6) sandstone; (7) marl; (8) chalk; (9) limestone; (10) pebble (*a*) and rubble (*b*); (11) phosphorite concretions (a) and pebbles (b); (12) ooliths; (13) siderite concretions; (14) glauconite; (15) pyrite; (16) ferruginate marks; (17) micaceous rocks; (18) calcareous rocks; (19) bituminous rocks; (20) charred wood fragments; (21) plant remains; (22) bioturbation; (23) algae; (24) ammonites; (25) belemnites; (26) brachiopods; (27) inocerams; (28) other bivalves; (29) gastropods; (30) sponges.

Foraminiferal assemblages: (IV) *Lenticulina cultratiformis–Lenticulina pseudocrassa*; (V) *Lenticulina tumida–Epistomina elschankaensis*; (VI) *Ophthalmidium sagittum–Epistomina volgensis*; (VII) *Ophthalmidium strumosum–Lenticulina brestica*; (VIII) *Epistomina uhligi–Lenticulina russiensis*; (IX) *Epistomina praetatariensis–Lenticulina kuznetsovae*; (X) *Pseudolamarckina pseudorjasanensis–Haplophragmium monstratus*; (XIII) *Lenticulina infravolgaensis–Saracenaria pravoslavlevi.*

Table 4. Position of the Vykhino Horizon in the regional scheme of the Russian platform

Stage	Substage	Regional scheme (1993)				Local units (formation)	Substage (this paper)
		Ammonite zone	Ammonite subzone	Foraminifer zone	Horizon		
Oxfordian	upper	*Amoeboceras alternoides*	*Amoeboceras alternoides*	*Epistomina uhligi – Lenticulina russiensis*	Kolomenskoe	Kolomenskoe	upper
			Amoeboceras ilovaiskii	*Ophthalmidium strumosum – Lenticulina brestica*	Vykhino	Podmoskovnaya	middle
	middle	*Cardioceras tenuserratum*	*Cardioceras (Miticardioceras)* spp.				
			Cardioceras zenaidae				
		Cardioceras densiplicatum	*Cardioceras densiplicatum*	*Ophthalmidium sagittum – Epistomina volgensis*		Rat'kovo	
			Cardioceras popilaniense				
	lower	*Cardioceras cordatum*			Podosinki (part)	Podosinki (part)	lower

This decision approved at the extended meeting of the IRSC bureau, was confirmed by the ISC Constant Commission on the Jurassic on January 30, 1998.

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Reviewer A.S. Alekseev

REFERENCES

Gerasimov, P.A., *Gastropody yurskikh i pogranichnykh nizhnemelovykh otlozhenii Evropeiskoi Rossii* (Gastropods of the Jurassic and Agjoining Lower Cretaceous Sediments in European Russia), Moscow: Nauka, 1992.

Gerasimov, P.A., Jurassic System, *Geologiya SSSR. T.IV. Tsentr Evropeiskoi chasti SSSR* (Geology of the Soviet Union, vol. 4: European part of the Soviet Union), Moscow: Nedra, 1971, pp. 373–416.

Gerasimov, P.A., Mitta, V.V., Kochanova, M.D., *et al.*, *Iskopaemye kelloveiskogo yarusa Tsentral'noi Rossii* (Fossils of the Callovian Stage in Central Russia), Moscow: Vseross. Nauchno-Issled. Gasa Nefti Inst., MosGorSYuN, 1996.

Grigyalis, A.A., Azbel', A.Ya., Alieva, D.G., *et al.*, *Biostratigrafiya yurskikh otlozhenii SSSR po foraminiferam* (Foraminiferal Biostratigraphy of the Jurassic Sediments in the Soviet Union), Vilnius: Mokslas, 1982.

Hantzpergue, P., Baudin, F., Mitta, V., *et al.*, Le Jurassique superieur du bassin de la Volga: biostratigraphie des faunes d'ammonites et correlations avec les zonation standards europeennes, *C.R. Acad. Sci. Paris, Sciences de la terre et des planetes*, 1998, no. 326, pp. 633–640.

Hantzpergue, P., Baudin, F., Mitta, V., *et al.*, The Upper Jurassic of the Volga Basin: Ammonite Biostratigraphy and Occurrence of Organic-Carbon Rich Facies. Correlation between Boreal–Subboreal and Submediterranean Provinces, Peri-Tethys. Memour 4: Epicratonic Basins of Peri-Tethyan Platform, Crasquin-Soleau, S. and Barrier, E., Eds., *Mem. Mus. Natur. Hist.*, 1998, vol. 179, pp. 9–33.

Mesezhnikov, M.S., Azbel', A.Ya., Kalacheva, E.D., *et al.*, *Srednii i verkhnii oksford Russkoi platformy* (Middle and Upper Oxfordian of the Russian Platform), Leningrad: Nauka, 1989.

Mesezhnikov, M.S., Kalacheva, E.D., and Rotkite, L.M., Distribution of Ammonites in the Middle–Upper Oxfordian Sediments of the Unzha River Basin (Makar'ev Reference Section), *Yurskie otlozheniya Russkoi platformy* (Jurassic Sediments of the Russian Platform), Leningrad: Vses. Nauch.-Issled. Geol.-Razved. Inst., 1986, pp. 145–154.

Resheniya Vsesoyuznogo soveshchaniya po utochneniyu unifitsirovannoi skhemy stratigrafii mezozoiskikh otlozhenii Russkoi platformy (Resolutions of All-Union Conference on Improvement of Unified Scheme for the Stratigraphy of Mesozoic Sediments in the Russian Platform), Gostoptekhizdat, 1962.

Sykes, R.M. and Callomon, J.H., The Amoeboceras Zonation of the Boreal Upper Oxfordian, *Palaeontology*, 1979, vol. 22, part 4, pp. 839–903.

The Jurassic Ammonite Zones of the Soviet Union. Special Papers Geological Society of America, V. Series, Krymholts *et al.*, Eds., 1988.

Unifitsirovannaya stratigraficheskaya skhema yurskikh otlozhenii Russkoi platformy (Unified Stratigraphic Scheme of the Jurassic Sediments of the Russian Platform), St. Petersburg: Vses. Nauchno-Issled. Geol.-Razved. Inst., Roskomnedra, 1993.

Zony yurskoi sistemy v SSSR (Zones of the Jurassic System in the Soviet Union), Krymgolts, G.Y., Ed., Leningrad: Nauka, 1982.

Stratigraphy and Geological Correlation, Vol. 9, No. 5, 2001, pp. 491–500. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 9, No. 5, 2001, pp. 77–86.
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New Data on Biostratigraphy of the Volgian Stage Lectostratotype near the Gorodishche Village (Middle Volga Region)

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Abstract—A thorough revision of the lectostratotype of the Volgian Stage near the Gorodishche Village (Ul'yanovsk region) and neighboring section of the upper Kimmeridgian–lower Volgian (Dubki Village) revealed the radiolarian assemblage with *Parvicingula jonesi* corresponding to the *cymodoce* and *eudoxus* ammonite zones. The radiolarian assemblage from the lower Volgian *klimovi* ammonite zone is dominated by *Parvicingula blowi*. Representatives of the genus *Parvicingula* prevail also in the *sokolovi* and *pseudoscythica* zones. The uppermost middle Volgian *Zarajskites zarajskensis* Zone and the *Dorsoplanites panderi* Zone contain the diverse radiolarian assemblage with *Parvicingula haeckeli*. The late Volgian radiolarian assemblage from the *subditus* ammonite zone includes abundant *Stichocapsa devorata* and is close to that from coeval sediments of the North Sea. In contrast to Kimmeridgian–Tithonian radiolarian assemblages of the Caucasus, the studied assemblages are of the boreal type. The *Virgatites gerassimovi* Zone is established and the scope of the *Virgatites virgatus* and *Epivirgatites nikitini* zones of the middle Volgian Substage is specified. The upper Volgian *Kachpurites fulgens* Zone is subdivided into subzones. The thorough study of the phosphorite horizon at the boundary between Volgian and Hauterivian stages did not confirm the presence of the upper Berriasian and lower Valanginian fossils even in the redeposited state.

Key words: Kimmeridgian and Volgian stages, Volga region, zone, condensed section, ammonites, radiolarians.

INTRODUCTION

Recently, Volgian and Kimmeridgian bituminous beds of the Volga region attracted a special attention (*Tsentral'nye raiony...*, 1984; Bukina *et al.*, 1987; Kuleva *et al.*, 1992, 1996; Vishnevskaya, 1998; Baudin *et al.*, 1996; Sedaeva and Vishnevskaya, 1995; Hantzpergue *et al.*, 1998; Turov, 1998).

Similar bituminous Upper Jurassic rocks are well known along the Uralian margin of the Barents Sea–Pechora depression (combustible shales), in West Siberia, where they are main constituents of the Bazhenovo productive horizon (Braduchan *et al.*, 1986, 1989; Kozlova, 1971, 1994), and from the North Sea (Dyer and Copestake, 1989). Of a great interest is a problem of the origin of the Volgian shaly sequence, as well as a problem of stratigraphic correlation of the Boreal Volgian Stage with its counterparts in the Tethyan province.

Nikitin (1881) was first to distinguish the Volgian Stage, and lectostratotype of the stage was selected by Gerasimov and Mikhailov (1966). It was considered for a long time that the Volgian Stage corresponds in its scope to the Tithonian Stage of the Mediterranean region (*Zony...*, 1982). Nevertheless, many researchers tend to believe that the upper Volgian Substage (partly or completely) corresponds to the lower Berriasian (Casey, 1973; Casey *et al.*, 1977; Hoedemaeker, 1987; Sei and Kalacheva, 1997; Baraboshkin *et al.*, 1999; and others). Precisely this point of view is accepted by the Interdepartmental Stratigraphic Committee of Russia (Zhamoida and Prozorovskaya, 1997). In view of controversial opinions, a thorough revision of the lectostratotype section of the Volgian Stage is of a particular scientific interest.

The lectostratotype of the Volgian Stage is exposed along the right bank of the Volga River downstream of the Gorodishche Village and 25 km upstream of Ul'yanovsk. Detailed descriptions of the section can be found in a series of works (Pavlov, 1884; Milanovskii, 1940; Gerasimov and Mikhailov, 1966; *Svodnyi putevoditel'...*, 1984; Kuleva *et al.*, 1992). The last one substantiated the stratigraphic incompleteness of the Gorodishche section, and its authors proposed a new lectostratotype for the *Dorsoplanites panderi* Zone distinguished in the Borehole 559 of the Perelyubskii area (eastern Volga River basin).

In their appearance and formation conditions, the lower–middle Volgian rocks of the lectostratotype represent a continuation of the Kimmeridgian part of the

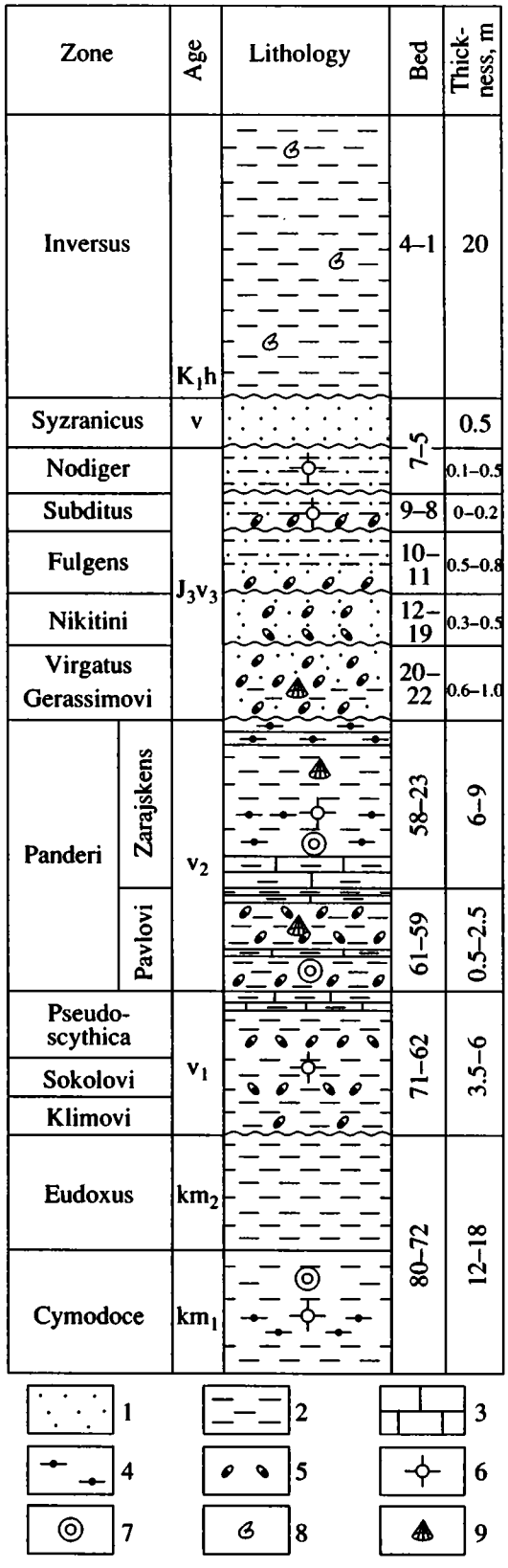

Fig. 1. The Gorodishche section and sampling sites of radiolarians: (1) sandstone; (2) clay; (3) limestone; (4) combustible shale; (5) pebble; (6) radiolarians; (7) nannoplankton; (8) ammonites; (9) buchias.

section, and they should be discussed in the context of general development of the basin. It is important that the Kimmeridgian sequence also encloses the high-bituminous horizon in the basal part of the section (Hantzpergue *et al.*, 1998) and bears Tethyan elements amid ammonite species (Gerasimov and Mikhailov, 1966; *Svodnyi putevoditel'...*, 1984; Baudin *et al.*, 1996; Hantzpergue *et al.*, 1998). The most complete upper Kimmeridgian section is exposed in the Dubki Village area, 9–10 km upstream of the Gorodishche section.

We studied sections exposed near the Gorodishche and Dubki villages during field works of 1995–1997 autonomously and in cooperation with researchers from the Geological Institute of the Russian Academy of Sciences, Scientific–Research Institute of the Saratov State University, and Simbirsk Geological–Prospecting Expedition of the Ministry of Mineral Resources of the Russian Federation.

DISTRIBUTION OF MACROFAUNA AND RADIOLARIANS

The Kimmeridgian sequence (Fig. 1) is composed of slightly calcareous light clays with rare members of dark-colored bituminous marls containing up to 15% of organic matter (Baudin *et al.*, 1996). The radiolarian assemblage is mainly represented by nasselarians, among which representatives of the genus *Parvicingula* are sharply dominant. The share of these forms amounts to 50–60% of total radiolarian abundance. Because fossils in the lower Kimmeridgian part of the section are poorly preserved, we were able to determine only *Parvicingula jonesi* Pessagno prevailing in the assemblage. A similar assemblage with preponderant *P. jonesi* Pessagno was previously registered in the lower Kimmeridgian *cymodoce* Zone of the North Sea (Dyer and Copestake, 1989).

In addition to radiolarians, the lower Kimmeridgian part of the section located 10 km north of the Gorodishche Village (the Mimei section after Hantzpergue *et al.*, 1998) yielded ammonites *Rasenia* cf. *cymodoce* (d'Orb.), *R.* (=*Zonovia*) cf. *uralensis* (d'Orb.), and others, as well as rare *Buchia concentrica* (Sow.) and other bivalves (Hantzpergue *et al.*, 1998). The faunal assemblage correlates this part of the section with the *Rasenia cymodoce* Zone of the uppermost lower Kimmeridgian.

The upper Kimmeridgian part of the section (Beds 80–72 corresponding to Beds 1–4 in the guidebook *Tsentral'nye raiony...*, 1984) was studied directly near the Dubki Sanatorium (6 km north of the Gorodishche Village) and also in the Gorodishche section proper. The section is largely composed of light gray calcareous clays with pyrite concretions, most of which developed after large ammonite shells. Concretions yield *Aulacostephanus eudoxus* (d'Orb.), *A. contejeani* (Thur.), *A.* cf. *yo* (d'Orb.), *Pararasenia hibridus* Ziegler, *Aspidoceras caletanum* (Opp.), *A.* ex gr. *quer-*

cynum (Hantz.), *A.* ex gr. *longispinum* (Sow.), and *Tolvericeras sevogodense* (Cont. et Hantz.) (Hantzpergue *et al.*, 1998). This part of the section corresponds to the upper Kimmeridgian *Aulacostephanus eudoxus* Zone.

Previously, ammonites *Aulacostephanus eudoxus, A. sublacertosus, Amoeboceras volgae*, and *A. subtilicostatum* were determined from clays of Bed 2 (according to the numeration system accepted in the excursion guidebook of the 27 IGC; *Tsentral'nye raiony* ..., 1984) in the Gorodishche lectostratotype. Because of poor preservation, only *Parvicingula* genus with species *R. jonesi* was determined amid radiolarians.

The overlying Kimmeridgian part of the section is composed of light gray calcareous clays and alternating dark and light gray clays. These rocks yield *Aulacostephanus autissiodorensis* (Cott.), *A. undorae* (Pavl.), *A. volgensis* (d'Orb.), and *Virgataxioceras fallax* (Ilov.) correlating host layers with the *Virgataxioceras fallax* Subzone of the *Aulacostephanus autissiodorensis* Zone.

The lower Volgian Substage is represented by alternating light and dark calcareous clays (Beds 71–62 or Beds 5–8 in *Tsentral'nye raiony*..., 1984) with phosphorites. Clays contain ammonites *Ilowaiskya klimovi* (Ilov. et Flor.), *I. sokolovi* (Ilov. et Flor.), *I. pseudoscythica* (Ilov. et Flor.), and *Haploceras* sp. characteristic of the *Ilowaiskya klimovi–Ilowaiskya pseudoscythica* zones of the lower Volgian. The radiolarian assemblage from the ammonite *klimovi* Zone of the Gorodishche section is dominated by the *Parvicingula* genus, in particular by *P. blowi* (Pessagno). This assemblage is most similar to that described from the upper Kimmeridgian–lower Volgian *eudoxus–elegans* ammonite zones of the North Sea (Dyer and Copestake, 1989). This is consistent with the standpoint of Hantzpergue *et al.* (1998) who correlate the lower Volgian Substage with the uppermost Kimmeridgian. Radiolarians are scarce in clays of the *eudoxus–elegans* zones, but phosphate concretions confined usually to erosional surfaces yield abundant representatives of the genus *Parvicingula*.

The analyzed distribution of ammonites in sediments of the middle Volgian *Dorsoplanites panderi* Zone revealed that the *Pavlovia pavlovi* (lower) and *Zarajskites zarajskensis* (upper) subzones defined by Gerasimov and Mikhailov (1966) are distinct owing to prevalence of one or another index species. In contrast, Mitta (1993) does not subdivide the *panderi* Zone into subzones. In the Volgian Stage sections located southerly (Kashpir, Saratov Volga region, North Caspian region), the situation is opposite: *Zarajskites* forms are sharply dominant. This phenomenon can be explained by climatic zoning of the Volgian time, and hence by the temperature control over ammonite distribution (Baraboshkin, 1999). We think it is reasonable therefore to retain subdivision of the *panderi* Zone into subzones (at least for the Middle–Upper Volga region).

The *pavlovi* Subzone (Beds 61–59 or Bed 9 in *Tsentral'nye raiony*..., 1984) is composed of clayey–calcareous rocks with thin layers of marcasite and small phosphate concretions confined to erosional surfaces. The rocks enclose following groups of fauna: ammonites *Pavlovia* sp., *Dorsoplanites* aff. *panderi* (d'Orb.), *D.* sp., *Zarajskites* cf. *tschernyschovi* (Mich.), *Z.* cf. *michalskii* Mitta, and *Z.* sp.; abundant rostra of belemnites *Lagonibelus (L.) parvula* Gust. concentrated usually along erosional surfaces; bivalves *Mesomiltha fischeriana* (d'Orb.), *Buchia russiensis* (Pavl.), *Oxytoma* sp., *Protocardia concinna* (Buch), and *Gresslya alduini* (Fish.); gastropods *Eucyclus* sp., and *Apporhais* sp.; brachiopods *Lingula* sp., *Russiella* sp., and *Rhynchonella loxiae* (Fisch.); and rare scaphopods *Laevidentalium* sp., and "*Serpula*" sp.

The *zarajskensis* Subzone (Beds 58–23 or Beds 10–11 in *Tsentral'nye raiony*..., 1984) encloses a more diverse fossil assemblage. It spans an interval composed of rhythmically alternating calcareous clays from the basal bed, showing dissolution and redeposition marks, to black bituminous shales at the top. The ammonite assemblage of *zarajskensis* Subzone includes species *Zarajskites* cf. *scythicus* (Vischn.), *Z. pilicensis* (Mich.), *Z. quenstedti* (Rouill. et Fahr.), *Z. stchukinensis, Dorsolplanites panderi* (d'Orb.), and *Pavlovia* sp. They associate with other faunal groups: belemnites *Lagonibelus* (L.) *magnifica* (d'Orb.), *L.* (*Holcobeloides*) *volgensis* (d'Orb.), and *L.* (*L.*) cf. *rosanovi* Gust.; bivalves *Astarte* sp, *Gresslya alduini* (Fisch.), *Buchia mosquensis* (Buch), *B. russiensis* (Pavl.), *Oxytoma* sp., *Mesomiltha fischeriana* (d'Orb.), *Nucula* sp., *Panopea* sp, *Limatula consobrina* (d'Orb.), and *Eucyclus* sp.; scaphopods *Laevidentalium* sp.; and brachiopods *Lingula* sp., *Rhynchonella rouillieri* Eichw., and others. Species *Berlieria maeotis* (Eichw.) is sharply prevalent in the upper part of the shaly section. It is accompanied by abundant young ammonite shells forming lens-like accumulations. The top of the shaly section is strongly eroded.

Among microfossils from the *Zarajskites zarajskensis* Subzone of the *Dorsoplanites panderi* Zone, there were discovered diverse radiolarians, abundant benthic foraminifers (Dain and Kuznetsova, 1976), and coccolithophorids (Nikiforova, 1986). The radiolarian assemblage includes *Orbiculiforma* ex gr. *mclaughlini* Pessagno, *Stichocapsa*? *devorata* (Rust), *Phormocampe favosa* Khudyaev, *Parvicingula hexagonata* (Heitzer), *P. cristata* Kozlova, *P. conica* (Khabakov), *P.* aff. *alata* Kozlova, *P. multipora* (Khudyaev), *P. haeckeli* (Pantanelli), *P.* aff. *spinosa* (Grill et Kozur), *Plathycryphalus? pumilus* Rust, and *Lithocampe* cf. *terniseriata* Rust. Like in the Kimmeridgian and early Volgian assemblages, sharply prevalent here are representatives of the genus *Parvicingula* that is characteristic of the Boreal province. Species of this genus constitute more than 50% of the assemblage (Plate).

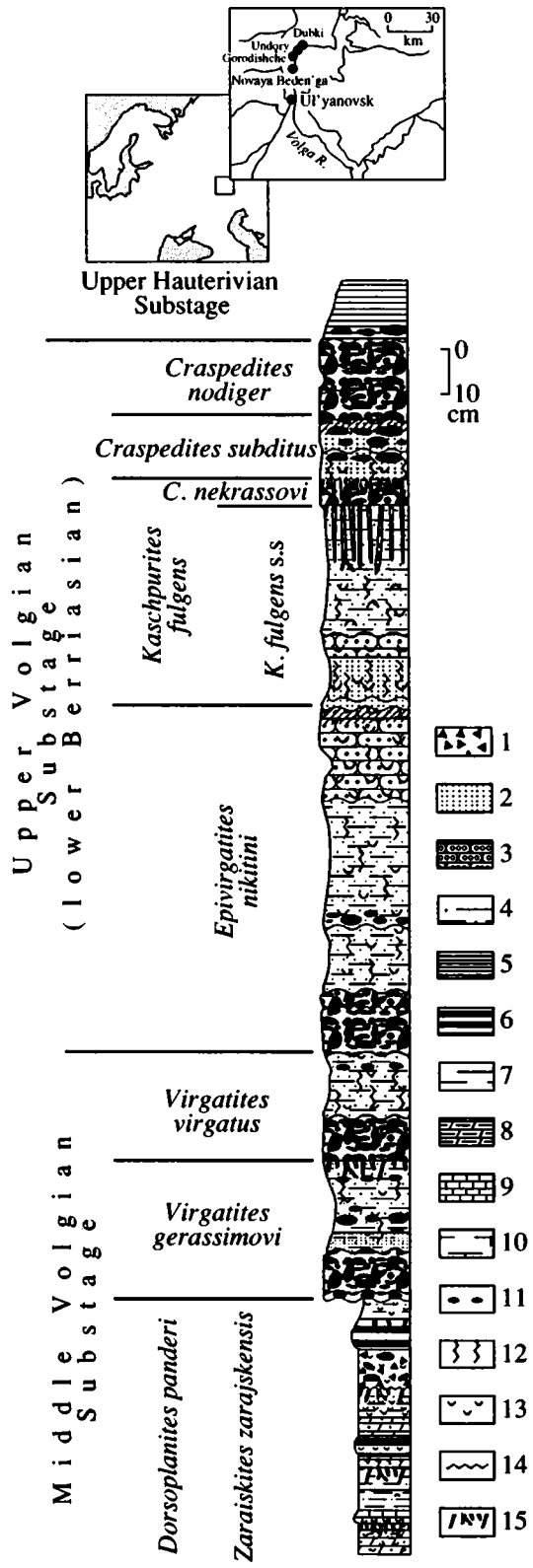

Fig. 2. Detailed section of the upper part of the Volgian Stage: (1) breccia; (2) sand; (3) sandstone; (4) siltstone; (5) clay; (6) combustible shale; (7) argillite-like clay; (8) marl, clayey marl; (9) limestone; (10) calcareous clay; (11) phosphorites; (12) bioturbation; (13) shelly detritus; (14) erosional surface; (15) "soft ground".

We refer the overlying interval (Beds 22–21 or Beds 12–13 in *Tsentral'nye raiony...*, 1984) to the *Virgatites gerassimovi* Zone that was previously ranked as subzone (Mitta, 1993). In our opinion, this unit lacking *Virgatites virgatus* s.s. is of a higher rank because of its sufficient distribution range (central areas of the Russian plain, Middle Volga and easterly regions). In the lectostratotype, this condensed zone corresponds to a member of loose quartz–glauconite sandstone with rounded phosphorite pebbles and "soft-ground" surface at the top. Basal phosphorite pebbles yield redeposited *Zarajskites* cf. *scythicus* (Vischn.) and *Pavlovia* sp., as well as abundant radiolarians occurring in clays of the underlying *zarajskensis* Subzone. Rounded and redeposited fragments of both zonal species *Virgatites gerassimovi* Mitta and *Virgatites virgatus* (Buch) were found, along with *Mesomiltha* sp. and rostra of *Lagonibelus* (H.) *volgensis* (d'Orb.), in phosphorite pebbles of several generations (Bed 20). Thus, the *gerassimovi* Zone is recognized based on its position in the section and on finds of redeposited index species at the base of the overlying zone. The thickness of the *gerassimovi* Zone is 0.35–0.45 m (Fig. 2).

As was mentioned, the *Virgatites virgatus* Zone (Beds 20–21 or Beds 13–14 in *Tsentral'nye raiony...*, 1984) begins with the phosphorite conglomerate member grading upward into greenish bioturbated quartz–glauconite sandstone with pyrite concretions. Sandstone is eroded at the top. The zone contains index species and is about 0.25–0.55 m thick (Fig. 2).

The *Epivirgatites nikitini* Zone (Beds 19–12 or Bed 15 in *Tsentral'nye raiony...*, 1984) is composed of gray bioturbated limy sandstone with the basal phosphorite conglomerate member containing redeposited *Virgatites virgatus* (Buch), *V. pusillus* (Mich.), and *V. pallasianus* (Mich.). One of several erosional surfaces distinguishable in the zone (the base of Bed 17) is marked by small-pebble phosphorite conglomerate. Remains of large to giant ammonites *Epivirgatites bipliciformis* (Nikitin) and *E. nikitini* (Mich.) occur at a higher level of the section. Radiolarians are missing from these sediments. The eroded roof is ocherous. The thickness of the zone is 0.3–0.5 m.

Higher in the section (Beds 11–10 or Beds 16–17 in *Tsentral'nye raiony...*, 1984), the erosional surface of the zone is overlain by the upper Volgian (lower Berriasian) clayey sandstones of the *Kachpurites fulgens* Zone. Sandstones enclose lenticular clayey interbeds, and abundant erosional surfaces are marked in this interval by accumulations of belemnite rostra. The upper part of the interval yields ammonites *Kachpurites fulgens* (Trautsch.) (Bed 11), *Craspedites nekrassovi* Prig., *C.* sp., bivalves *Buchia piochii* (Gabb.), belemnites *Acroteuthis* (A.) *russiensis* (d'Orb.) and *A.* (A.) *mosquensis* (Pavl.) (Bed. 10). By analogy with the Kashpir section (Gerasimov and Mikhailov, 1966; Gerasimov, 1969), one can assume that the *fulgens* Zone (Baraboshkin, 1999) consists of two *Kachpurites*

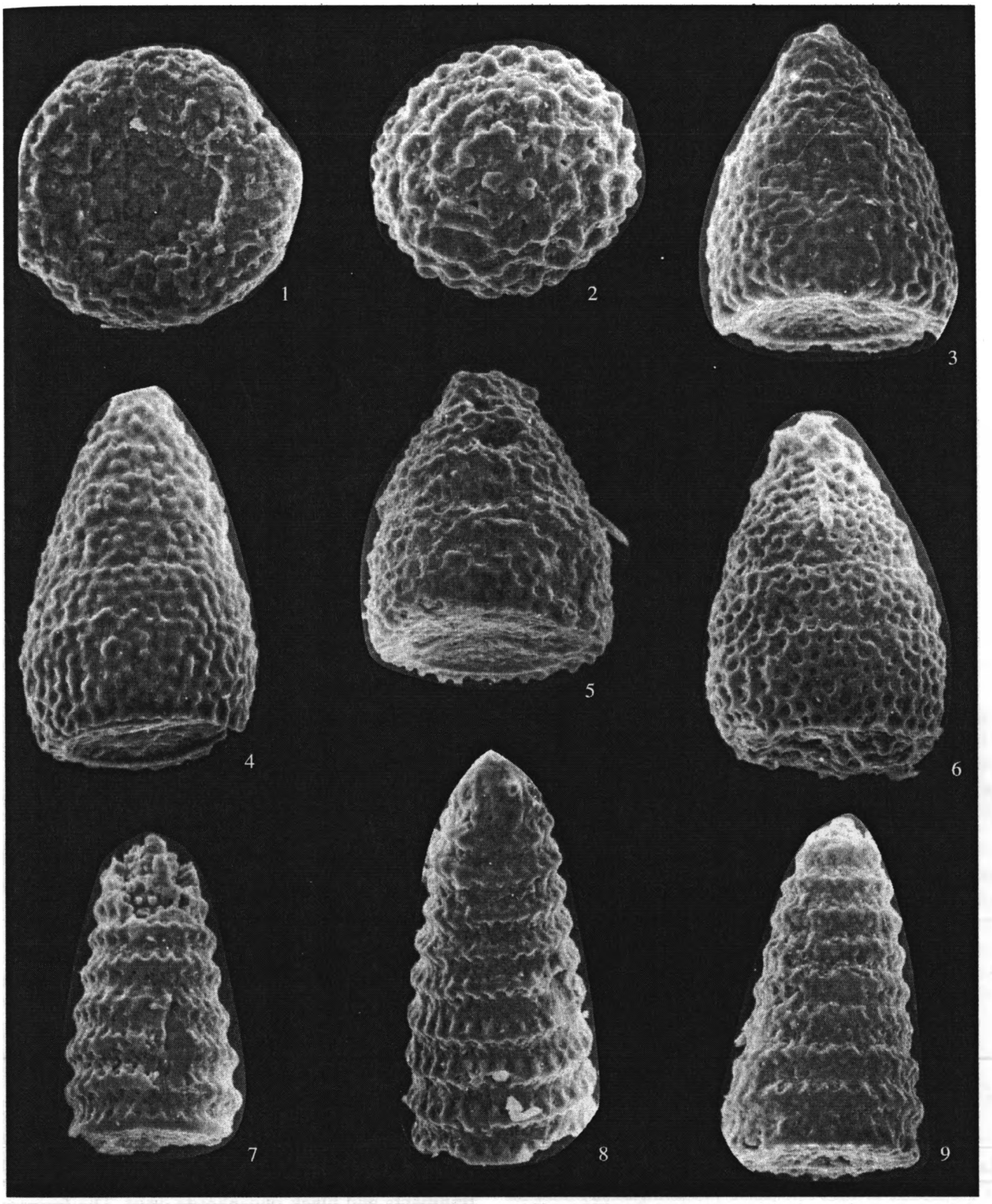

Plate. Radiolarians from the Volgian Stage of the Gorodishche section: (1) *Orbiculiforma* ex gr. *mclaughlini* Pessagno; (2) *Praeconocaryomma* sp.; (3) *Stichocapsa devorata* (Rust); (4) *Parvicingula hexagonata* (Heitzer); (5, 6) *P. cristata* Kozlova; (7–9) *P.* aff. *alata* Kozlova. Magnification for all specimens is 400. Distribution through the section: (1–7) upper Volgian Substage, (8, 9) middle Volgian Substage.

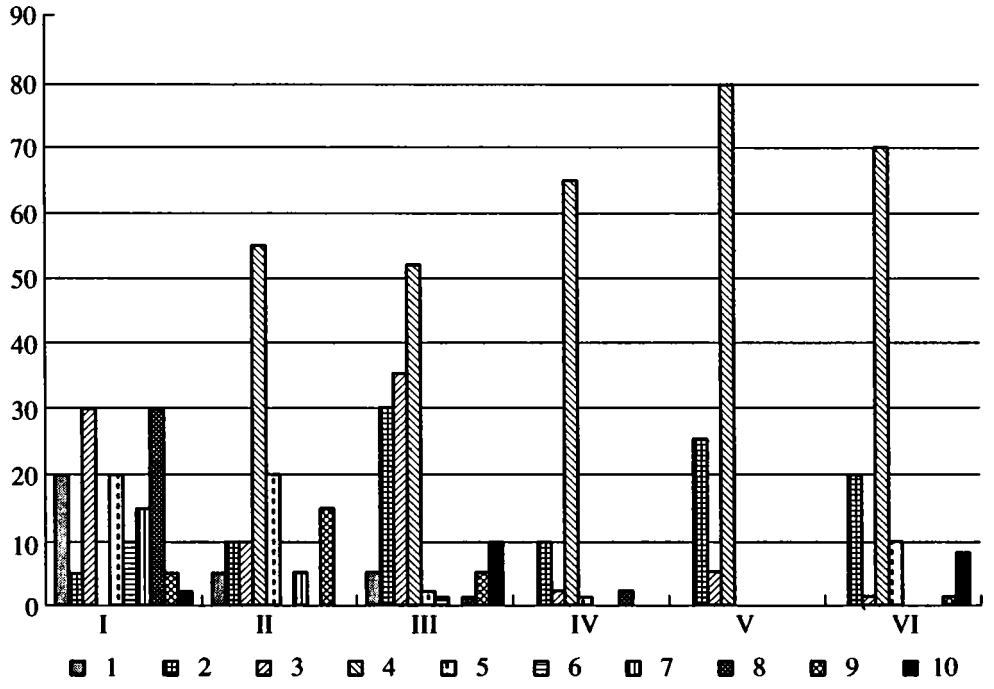

Fig. 3. Quantitative distribution of Kimmeridgian–Volgian and Kimmeridgian–Tithonian radiolarian high-rank taxa in different regions: (I) Alps, (II) California, (III) Antarctica, (IV) Volga region, (V) Barents Sea, (VI) Bering Sea. Radiolarian series: (1) Perispyridae, (2) Orbiculiformidae, (3) Pantanellidae, (4) *Parvicingula*, (5) Hsuidae, (6) Xitidae, (7) *Ristola*, (8) *Tethysetta*, (9) *Napora*, (10) *Amphipyndax*.

Histograms show maximum abundance rates of taxa. For instance, the content of genus *Ristola* in the Alps varies from 5 to15% and the histogram shows its maximum value, i.e., 15%.

fulgens s.s. (Bed 11) and *Craspedites nekrassovi* (Bed 10) subzones. The base and top of Bed 10 are marked by "soft-ground" surfaces with crustacean burrows penetrating down to a depth of 10–30 cm. The thickness of the *fulgens* Zone is 0.5–0.8 m (Figs. 1, 2).

Overlying quartz–glauconite sandstones (Bed 9–8 or Beds 17–18 in *Tsentral'nye raiony...*, 1984) rest also upon the erosional surface of the previous zone, and their basal part encloses rounded pebbles of phosphatic sandstone with redeposited coarsely ribbed *Kachpurites* sp. found in association with bivalves *Buchia piochii* (Gabb), *B.* sp., and *Entolium* sp. Bed 8 yields poorly rounded phosphatized fragments of ammonites *Craspedites* cf. *okensis* (d'Orb.). This form is most typical of the *Craspedites subditus* Zone, but can occur also in the upper part of the *fulgens* Zone (Gerasimov, 1969; Baraboshkin, 1999). No specimens of *Kachpurites* were found in this member that yields only abundant rostra of belemnites *Acroteuthis* (A.) *mosquensis* (Pavl.) and bivalves *Buchia piochii* (Gabb) and *B. tenuicollis* Pavl.). This part of the section should probably be referred to the *Craspedites subditus* Zone, because its zonal species was previously noted in corresponding sediments (Gerasimov and Mikhailov, 1966). The apparent thickness of the zone, the roof of the which is eroded, is up 0.2 m (Figs. 1, 2).

Calcareous clays from Bed 8 enclose the radiolarian assemblage of *Orbiculiforma* sp., *Praeconocaryomma* sp., *Parvicingula cristata* Kozlova, *P. alata* Kozlova, *P. blowi* (Pessagno), *Spinicingula* sp., and *Stichocapsa devorata* (Rust.). The latter species is particularly abundant. In the appearance, it is similar to the morphotype described from the North Sea (Dyer and Copestake, 1989). Like in the underlying sediments, the radiolarian assemblage is dominated by parvicingulids representing up to 50–60% of all specimens.

Beds 7–5 (or Beds 18–19 in *Tsentral'nye raiony...*, 1984) crowning sections of the Volgian Stage represent a succession of three phosphorite conglomerate layers separated by erosional surfaces. The lower conglomerate layer (0.12 m) encloses abundant rostra of belemnite *Acroteuthis* sp., bivalves *Buchia* sp., and *Pleuromya* sp. as well as redeposited phosphorite casts of ammonite *Craspedites* cf. *okensis* (d'Orb.). The middle conglomerate layer (0.1 m) that is softer forms a recess in the exposure surface. The upper conglomerate layer (0.1 m) is hardest consisting of large "hard-ground" fragments and black phosphorite crust. The fragments yield phosphatized remnants of *Craspedites parakaschpuricus* Geras. and *Buchia volgensis* (Lah.). The find of *Nikitinoceras* (=*Temnoptychites*) *mokschensis* (Bog.) frequently cited in publications (Gerasimov and Mikhailov, 1966; *Tsentral'nye raiony...*, 1984) originates most likely from the same layer. During our thor-

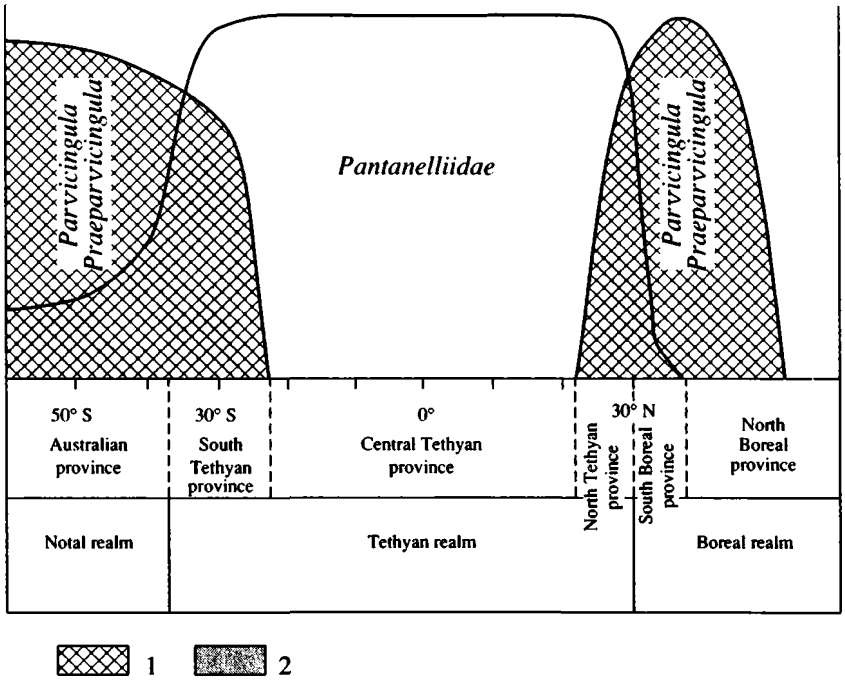

Fig. 4. Quantitative distribution of *Parvicingula* (1) and Pantanellidae (2) representatives in different provinces versus paleolatitudes (after Kiessling and Scasso, 1996).

ough search in the Gorodishche and Slantsevyi Rudnik (several kilometers downstream of the Volga River) sections, we failed to find either Berriasian or Valanginian ammonites. Therefore, we refer the considered sediments to the *Craspedites nodiger* Zone. Taking into consideration the abundant hiatuses and lenticular structure of this part of the section, we think that sediments referred to the *Temnoptychites syzranicus* Zone (lower Valanginian) could be preserved in the section studied by Gerasimov and Mikhailov (1966). Phosphorites yield radiolarians *Parvicingula boesii* (Parona), a species widespread in the Tithonian–Valanginian sequences of the Mediterranean belt. Previously (Vishnevskaya *et al.*, 1990), this species was also identified in the Tithonian deposits of the western Dagomys area (Greater Caucasus).

The section is crowned by black clays (Beds 4–1 or Bed 20 in *Tsentral'nye raiony...*, 1984) with siderite and limonite concretions enclosing large ammonites *Speetoniceras* (*S.*) *versicolor* (Trautsch.) and *S.* (*S.*) *subinversum* (M. Pavl.,) characteristic of the upper Hauterivian *Speetoniceras* (*S.*) *versicolor* Zone (Chernova, 1951) that was previously defined as the *Speetoniceras inversus* Zone.

CHARACTERISTIC OF THE RADIOLARIAN ASSEMBLAGE

At several stratigraphic intervals, fossils with calcareous skeletons coexist with abundant siliceous microfossils (radiolarians and sponge spicules). It is important that siliceous microplankton (radiolarians) in the *zarajskensis* Zone occurs together with calcareous plankton (coccolithophorids) and juvenile forms of benthic (*Mesomiltha, Berlieria*) and nektonic ammonites.

Notwithstanding the fact that radiolarians were previously recorded in the Kimmeridgian–Volgian interval of the Gorodishche section (Dain and Kuznetsova, 1976), but their assemblage was never studied in detail. Radiolarians were also noted in coeval sediments of the Pechora basin and in the Bazhenovo Formation of West Siberia, where they form considerable local accumulations (Kozlova, 1983, 1984).

Abundance of radiolarians throughout the Gorodishche section conflicts with the assumption that the Volgian basin was extremely shallow and insufficiently saline (Kuleva *et al.*, 1996). Our data favor better the standpoint of Strakhov (1936, 1937) who suggested the normal salinity and gas regime for the basin. To substantiate this assumption, he mentioned mass accumulations of various shelly organisms in combustible shales (Strakhov, 1937). He emphasized that virtually every sample contained organic remains, and that one square meter of the exposure demonstrates up to 160 imprints of *Orbiculoidea maeotis* Eichw. according to assessment of A.N. Rozanov.

Unlike the Kimmeridgian–Tithonian radiolarian assemblages of the Caucasus (Vishnevskaya *et al.*, 1990), those from the Gorodishche section show a great similarity with the Boreal–Atlantic assemblages of the North Sea (Dyer and Copestake, 1989), Barents Sea–

Pechora region (Kozlova, 1983, 1994; Vishnevskaya, 1998) and with Arctic–Boreal assemblages of northern Siberia (Vishnevskaya and Malinovskii, 1995). Thus, they are of the boreal type. Abundant representatives of the genus *Parvicingula* prevailing in the studied radiolarian assemblage indicate its origin in the Boreal province (Pessagno *et al.*, 1986; Hull, 1995; Kiessling and Scasso, 1996), thus casting doubts on the thermophilic affinity of the fauna from bituminous Volgian shales of the *panderi* Zone in the Middle Volga region (Kuleva *et al.*, 1996). Our materials are completely compatible with previous data on other faunal groups, first of all on ammonites (Gerasimov and Mikhailov, 1976; Dain and Kuznetsova, 1976; *Zony...*, 1982; Braduchan *et al.*, 1986, 1989; Hantzpergue *et al.*, 1998; Baraboshkin, 1999; and others). It is most likely that the Gorodishche section encloses boreal assemblages with single thermophilic elements, and this is an obstacle impeding correlation between the Volgian and Tithonian stages. As is known, thermophilic *Haploceras* forms of the Tithonian occur only in the uppermost *panderi* Zone of the North Caspian region. In the Middle Volga region, Tethyan ammonites disappear at the top of the *panderi* Zone and only single Kimmeridgian and early Tithonian ammonites of Tethyan affinity are registered in this area (Repin and Rashvan, 1995).

Parvicingulids permanently constituting up to 50–60% of radiolarian assemblages (Fig. 3) represent a good indicator of upwelling (Vishnevskaya, 1996) and boreal influence (Fig. 4). Figure 3 demonstrates that the abundance rate of the genus *Parvicingula* is 70–80% in the Barents and Bering seas and 50% or more in Antarctica and flysch deposits of California, whereas its share is below 1% in Alpine sections. Thus, histograms showing distribution of high-rank radiolarian taxons within low and high latitudes are substantially different. Similarity in distribution patterns of radiolarians is especially characteristic of northern Russia. Radiolarian assemblages from the North Atlantic province (Barents Sea, Volga region) show a greater similarity between each other than with their counterparts from the Pacific province (see histograms of radiolarian distribution in California, Antarctica, and Bering Sea). In the latter province, distribution patterns are characterized by their own peculiarities. They are bimodal in character and show prevalence of *Parvicingula* forms.

Paleotemperature estimated from occurrence of belemnites in association with radiolarians show that waters in the North, Pechora, and Volga (Gorodishche) seas were heated up to 14–17°C during the Kimmeridgian and Volgian times, whereas temperature in the North Caspian sea was about 20°C during the Volgian time (Riboulleau *et al.*, 1998).

Sponge spicules from the middle Volgian layers of the Gorodishche section are largely represented by short fragments of calcareous and siliceous–keratose forms, although present are also thin long transparent spicules of a strictly regular geometric form belonging to glassy sponges. Finds of the latter serve as an additional argument favoring the normal salinity of the basin.

CONCLUSION

New biostratigraphic data obtained for the Gorodishche section allow the following to be stated:

(1) The *Virgatites gerassimovi* Zone is proposed and the scope of the *Virgatites virgatus* and *Epivirgatites nikitini* zones of the middle Volgian Substage is specified. The upper Volgian (lower Berriasian) *Kachpurites fulgens* Zone is subdivided into subzones traceable also in the Kashpir section; the scope of this zone is specified as well. The presence of lower Valanginian strata in the Gorodishche section is not confirmed.

(2) The Jurassic–Cretaceous (middle–upper Volgian) boundary is marked by the change in dominant species of radiolarian assemblages: representatives of the genus *Parvicingula* prevail in the Jurassic part of the section and *Stichocapsa* forms, in the Cretaceous one. Radiolarian assemblages from the Ul'yanovsk Volga region show a high similarity with those from coeval successions of the Pacific province.

(3) The same *Parvicingula* species (*P. alata, P. conica, P. cristata, P. multipora*), occurring in the boreal Barents Sea–Pechora–West Siberia basin and subboreal Moscow–Middle Volga basin, and species *P. hexagonata, P. spinose*, and *Stichocapsa devorata*, which are known from boreal sections of West Europe (Hetzer, 1931; Dyer and Copestake, 1989) and from the Middle Volga region, suggest the boreal character of the Kimmeridgian–Volgian basin of the East European platform. This basin was under significant or even prevalent influence of the Arctic Ocean or cold Arctic currents during formation of Kimmeridgian and Volgian strata of the Gorodishche section.

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REFERENCES

Baraboshkin, E.J., Berriasian–Valanginian (Early Cretaceous) Sea-Ways of the Russian Platform Basin and the Problem of Boreal/Tethyan Correlation, *Geol. Carpathica*, 1999, vol. 50, no. 1, pp. 1–16.

Baudin, F., Hantzpergue, P., Mitta, V., Olferiev, A., and Zakharov, V., Biostratigraphic Correlations and Black Shale Deposition of the Upper Jurassic from the Russion Platform, *Abstracts of the Peri-Tethyan Meeting*, Elsevier, 1996, p. 7.

Braduchan, Yu.V., Gol'bert, A.V., Gurari, F.G., *et al.*, The Bazhenov Horizon of Western Siberia (Stratigraphy, Ecosystem, Oil and Gas Resources), *Tr. Inst. Geol. Geofiz. Akad. Nauk SSSR, Sibirsk. Otd.*, 1986, issue 649.

Braduchan, Yu.V., Zakharov, V.A., and Mesezhnikov, M.S., Stratigraphy and Formation Conditions of Upper Jurassic–Neocomian Bituminous Deposits in the European Part of the Soviet Union and Western Siberia, *Osadochnaya obolochka Zemli v prostranstve i vremeni. Stratigrafiya i paleontologiya* (The Earth's Sedimentary Shell in Space and Time: Stratigraphy and Paleontology), Moscow: Nauka, 1989, pp. 108–115.

Bukina, T.F. and Yanochkina, Z.A., Principles of Rocks Typification in the Upper Jurassic Shale-Bearing Sequence of the Volga River Basin, *Litologiya, uglenosnost' i rudogenez osadochnykh tolshch Evropeiskogo Severo-Vostoka SSSR* (Lithology, Coal Resources, and Ore Genesis in Sedimentary Sequences of the Northeast European Soviet Union), Syktyvkar: Komi Filial Akad. Nauk SSSR, 1987, pp. 31–34.

Casey, R., The Ammonite Succession at the Jurassic-Cretaceous Boundary in Eastern England, *The Boreal Lower Cretaceous, Geological Journal Special Issue, no. 5*, Liverpool, Seel House Press, 1973, pp. 193–266.

Casey, R., Mesezhnikov, M.S., and Shul'gina, N.I., Comparison of the Jurassic–Cretaceous Boundary Sediments of England, Russian Platform, Subpolar Urals, and Siberia, *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1977, no. 7, pp. 14–33.

Chernova, E.S., On the Age and Subdivision of *Simbirskites* Beds and Belemnite-Bearing Rocks in the Volga River Region, *Byul. Mosk. Obshch. Ispyt. Prir., Otd. Geol.*, 1951, vol. 26, no. 6, pp. 46–81.

Dain, L.G. and Kuznetsova, K.I., *Foraminifery stratotipa volzhskogo yarusa* (Foraminifera of the Volgian Stage Stratotype), Moscow: Nauka, 1976.

Dyer, R. and Copestake, P., A Review of Latest Jurassic to Earliest Crataceous Radiolaria and Their Biostratigraphic Potential to Petroleum Exploration in the North Sea, *Northwest European Micropaleontology and Palynology*, London, 1989, pp. 214–235.

General Guidebook to Excursions 059, 060, 066 of XXVII International Geological Congress. Trip 060: the Jurassic–Cretaceous Boundary Layers in the Central Volga Region and Ryazan' District, *Tsentral'nye raiony evropeiskoi chasti RSFSR* (Central Regions of the European Part of the Soviet Russia), Moscow: Nauka, 1984, pp. 38–49.

Gerasimov, P.A., *Verkhnii pod"yarus volzhskogo yarusa tsentral'noi chasti Russkoi platformy. Paleontologo-stratigraficheskoe i litologicheskoe issledovanie* (The Upper Volgian Substage in the Central Russian Platform), Moscow: Nauka, 1969.

Gerasimov, P.A. and Mikhailov, N.P., The Volgian Stage and General Scale of the Upper Series of the Jurassic System, *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1966, no. 2, pp. 118–138.

Hantzpergue, P., Baudin, F., Mitta, V., Olferiev, A., and Zakharov, V., The Upper Jurassic of the Volgian Basin: Ammonite Biostratigraphy and Occurrence of Organic-Carbon Rich Facies. Correlations Between Boreal-Subboreal and Submediterranean Provinces, *Peri-Tethys. Memoir 4. Epicratonic Basins of Peri-Tethyan Platforms. Mem. Mus. National d'Hist. Nat.*, 1998, vol. 179, pp. 9–33.

Heitzer, I., Die Radiolarienfauna Der mitteljurassischen Kieselmergel Im Sonnwendgebirge, *Jahrb. Geol.*, 1930, no. 80, pp. 381–406.

Hoedemaeker, P.J., Correlation Possibilities around the Jurassic/Cretaceous Boundary, *Scripta Geologica, Publ. Netherlands Nat. Mus. Geol. Mineral. Leiden.*, 1987, vol. 84, pp. 1–64.

Hull, M.D., Morphologic Diversity and Paleogeographic Significance of the Family Parvicingulidae (Radiolaria), *Micropaleontology*, 1995, vol. 41, no. 1, pp. 1–48.

Kiessling, W. and Scasso, R., Ecological Perspectives of Late Jurassic Radiolarian Faunas from the Antarctic Peninsula, *Geo Research. Forum, Switzerland*, 1996, vols. 1, 2, pp. 317–326.

Kozlova, G.E., Mesozoic Radiolarian Assemblage of the Timan-Pechora Oil Field, *Proc. St.Petersburg Int. Conf.: Prospecting, Exploration, and Production of Oil and Gas in the Timan–Pechora Basin and Barents Sea*, St. Petersburg, 1994, pp. 60–75.

Kozlova, G.E., Occurrence of Radiolaria in the Bazhenov Formation of the Western Siberia, *Paleogeografiya i biostratigrafiya yury i mela Sibiri* (Paleogeography and Biostratigraphy of the Jurassic and Cretaceous in Siberia), Moscow: Nauka, 1983, pp. 47–55.

Kozlova, G.E., On Radiolaria Found in the Lower Kimmeridgian sediments of the Timan-Urals Region, *Dokl. Akad. Nauk SSSR*, 1971, vol. 201, no. 5, pp. 1175–1177.

Kuleva, G.V., Baryshnikova, V.I., Yanochkina, Z.A., *et al.*, *Gipostratotip zony Dorsoplanites Panderi Volzhskogo slantsenosnogo basseina* (Hypostratotype of the *Dorsoplanites panderi* Zone in the Volgian Shale-Bearing Basin), Available from VINITI, 1992, Moscow, no. 1242-V-92.

Kuleva, G.V., Yanochkina, Z.A., and Bukina, T.F., Paleoecosystem of *Dorsoplanites panderi* Phase in the Volga Shale-Generating Basin, *Stratigr. Geol. Korrelyatsiya*, 1996, vol. 4, no. 3, pp. 30–37.

Milanovskii, E.V., *Ocherk geologii Srednego i nizhnego Povolzh'ya* (Outline on Geology of Central and Lower Volga Region), Moscow: Gostoptekhizdat, 1940.

Mitta, V.V., *Ammonity i zonal'naya stratigrafiya srednevolzhskikh otlozhenii Tsentral'noi Rossii* (Ammonites and Zonal Stratigraphy of the Middle Devonian in Central Russia), Kiev: Nauk. Dumka, 1993.

Nikiforova, E.V., Nannoplankton-Based Subdivision of the Upper Kimmeridgian and Volgian Sediments in the Central Volga River Region, *Yurskie otlozheniya Russkoi platformy* (Jurassic Deposits of the Russian Platform), Leningrad: Nedra, 1986, pp. 172–180.

Nikitin, S.N., Jurassic Formations between Rybinsk, Mologa and Myshkin, *Mater. Geolkoma Rossii*, 1881, vol. 10, pp. 3–31.

Pavlov, A.P., The Jurassic of the Lower Volga River region, Geological Outline, *Zap. Spb. Mineral. O–va*, 1884, vol. 19, pp. 1–18.

Pessagno, E.A., Jr., Longoria, J.F., McLeod, N., and Six, W.M., Studies of North American Jurassic Radiolaria. Part I. Upper Jurassic (Kimmeridgian–Upper Tithonian) Pantanelliidae from the Taman Formation, East-Central Mexico: Tectonostratigraphic, Chronostratigraphic and Phylogenetic Implications, *Special Publ. Cushman Foundation Foram. Res.*, 1987, no. 23, pp. 1–55.

Repin, Yu.S. and Rashvan, N.Kh., *Kelloveiskie ammonity Saratovskogo Povolzh'ya i Mangyshlaka* (Callovian Ammonites in the Volga Region near Saratov and Mangyshlak), St. Petersburg: Mir i Sem'ya, 1995, pp. 4–21.

Riboulleau, A., Baudin, F., Daux, V., *et al.*, *Evolution de la paleotemperature des eaux de la plateforme russe au cours*

du Jurassique superieur, Acad. Sci. Paris: Sci. terre et planetes, 1998, no. 326, pp. 239–246.

Sasonova, I.G. and Sasonov, N.T., The Jurassic–Cretaceous Boundary in the East European Platform, *Aspekte der Kreide Europas, IUGS. Series A, no. 6*, Stuttgart, 1979, pp. 487–496.

Sedaeva, G.M. and Vishnevskaya, V.S., Jurassic Paleoenvironments in the North-Eastern European Platform, *Zonenshain Conference on Plate Tectonics*, Kiel: GEOMAR, 1995, p. 205.

Sei, I.I. and Kalacheva, E.D., The Jurassic–Cretaceous Boundary in the Boreal Realm (Biostratigraphy and Boreal–Tethyan Correlation), *Stratigr. Geol. Korrelyatsiya*, 1997, vol. 5, no. 1, pp. 42–59.

Strakhov, N.M., On Significance of Hydrosulfide Basins for Accumulation of Bituminous Formations and "Oil-Productive" Formations, *Izv. Akad. Nauk SSSR*, 1937, no. 5, pp. 893–917.

Strakhov, N.M., To Lithology of the Domanik Horizon, *Tr. Mosk. Geol.-Razv. Inst.*, 1936, vol. 1, pp. 58–90.

Tsentral'nye raiony evropeiskoi chasti RSFSR. Svodnyi putevoditel' ekskursii 059, 060, 066 (Central Regions of the European Part of the Soviet Russia. General Guidebook of Excursions 059, 060, and 066), Moscow: Nauka, 1984.

Turov, A.V., Structural Features of the Upper Jurassic Shale-Bearing Sequences in the Russian Plate, *Izv. Vyssh. Uchebn. Zaved., Geol. Razved.*, 1998, no. 2, pp. 71–78.

Vishnevskaya, V.S., Radiolaria of the Peri-Tethys and Their Stratigraphic Implication, *Dokl. Akad. Nauk*, 1996, vol. 346, no. 5, pp. 638–641.

Vishnevskaya, V.S., The Domanikoid Facies of the Russian Platform and Basin Paleogeography, *Geodiversitas*, 1998, vol. 177, pp. 45–69.

Vishnevskaya, V.S. and Malinovskii, Yu.N., *Nakhodka radiolyarii v opornom razreze oksford-valanzhinskikh otlozhenii na p-ve Paksa, Anabarskii zaliv, sever srednei Sibiri. Tezisy Mikropaleontologicheskogo obshchestva* (Radiolaria Found in the Reference Section of the Oxfordian–Valanginian Sediments of the Paksa Peninsula, Anabar Gulf, Northern Part of Central Siberia), Tomsk: Tomsk. Univ., 1995.

Vishnevskaya, V.S., Agarkov, Yu.V., Zakariadze, G.S., and Sedaeva, G.M., The Late Jurassic–Cretaceous Radiolaria from the Greater Caucasus as a Key to Interpretation of Age and Formation Settings of Ophiolites in the Lesser Caucasus, *Dokl. Akad. Nauk SSSR*, 1990, vol. 310, no. 6, pp. 1417–1421.

Zhamoida, A.I. and Prozorovskaya, E.L., Resolution Verifying the Jurassic–Cretaceous Boundary Position in the Boreal Region and Status of the Volgian Stage, *Postanovleniya Mezhvedomstvennogo stratigraficheskogo komiteta i ego postoyannykh komissii. Mezhvedomstvennyi stratigraficheskii komitet, S-Pb* (Resolutions of Interdepartmental Stratigraphic Commitee and Its Continuous Commissions. Interdepartmental Stratigraphic Commitee), St. Petersburg: Vses. Geol. Inst., 1997, issue 29, pp. 5–7.

Zony yurskoi sistemy v SSSR (Zones of the Jurassic System in the Soviet Union), Leningrad: Nauka, 1982, vol. 20.

Stratigraphy and Geological Correlation, Vol. 9, No. 5, 2001, pp. 501–507. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 9, No. 5, 2001, pp. 87–93.
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The Late Paleocene Ecologic Crisis in Epicontinental Basins of the Eastern Peritethys: Microbiota and Accumulation Conditions of Sapropelic Bed

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Abstract—In the Upper Paleocene sedimentary sequence of the Eastern Peritethys, there is a bed highly enriched in organic matter (sapropel). Investigation of microbiota, mainly of foraminifers, showed that the bed accumulated in response to paleoecologic crisis related to substantial oxygen deficiency in the paleobasin, which led to a significant extinction of benthic fauna. The true anoxic environments and related contamination by hydrogen sulfide have not been realized however. A vast transgression in the Eastern Peritethys appears to be the likely reason for the sediment enrichment in organic matter. This event caused submergence of a swampy coastal plain, subsequent active inflow of biophile elements, and abundance outburst of organic-walled phytoplankton and cyanobacteria.

Key words: Eastern Peritethys, Paleocene, sapropel, microbiota, quasi-anoxic environments, ecologic crisis.

INTRODUCTION

A long-standing research by N.G. Muzylev on the Upper Paleocene sedimentary sequence in the south of the former USSR showed the occurrence of a thin bed (less than 1 m thick as a rule) considerably enriched in organic matter and designated here as sapropelite. It is commonly consists of dark-colored to black, fine-foliated, clayey, usually calcareous deposits often bearing abundant fish remains. The stratigraphic position of the sapropelic bed is reliably defined in the nannoplankton zonal scale. In the most complete sections, the boundary between the *Chiasmolithus bidens* CP8a and *Campylosphaera eodela* CP8b subzones of the *Discoaster multiradiatus* CP8 Zone is recognized within this sapropelic bed. According to planktonic foraminifers, the bed corresponds to the upper part of the *Acarinina acarinata* Zone of the Crimea–Caucasus' scale. In some cases, it yields planktonic foraminifer *Morozovella aequa* (Cushman et Renz), and this was regarded as a basis for the recognition of the synonymous foraminiferal zone (Shutskaya, 1970; Muzylev *et al.*, 1989). In our opinion, the bed is actually traceable within a limited area, and the recognition is of the ecological significance only.

Originally, the sapropelite origin was considered as a consequence of anoxic environments in the basin followed by hydrogen sulfide contamination of bottom waters (Muzylev *et al.*, 1989; Gavrilov and Muzylev, 1991; Muzylev, 1994; Gavrilov *et al.*, 1997). That conclusion was thought to be compatible with presence of nothing but planktonic biota in the sediments. Later on, the detailed study of sections revealed that benthic foraminifers are common though not predominant components of the sapropelite biota. We are doing to show that true anoxic conditions have not been characteristic neither of the basin, nor of its bottom waters. At the same time, just-accumulated and still unlithified bottom deposits were quite evidently characterized by reducing conditions, as it is evident from geochemical peculiarities of sediments under discussion (Gavrilov *et al.*, 1997). Accordingly, the term "quasi-anoxic conditions" that we use here signifies the water regime with a lowered concentration of dissolved oxygen, though it was sufficient for activity of aerobic organisms.

We studied the following 13 sections with the upper Paleocene sapropelic bed (Figs. 1 and 2): along the Malyi Zelenchuk, Kuban', Baksan, and Kheu rivers (central Ciscaucasia); near the Medani Village (western Georgia); in the Kizil-Cheshme and Torangly tracts (western Kopet-Dag); at the Aktumsuk Cape (eastern Ustyurt, the western shore of the Aral Sea); in the Guru-Fat'ma and Kurpai tracts (Tajik Depression); near the Ak-Tash Village (southwestern spur of the Gissar Ridge); and along the Isfara and Shor-Su rivers (Fergana depression). In the most complete sections at the Kheu, Kizil-Cheshme, Torangly, Aktumsuk-1 and 2, Kurpai, Isfara, and Shor-Su sites, the sapropelite bed is of three-member structure. Its lower part of darkest color shows the maximum C_{org} content; sediments in the middle part are lighter, but become darker again in the upper one though to a lesser degree than in basal portion. We should emphasize that these lithologic variations are not always accompanied by changes in foraminiferal paleocoenoses.

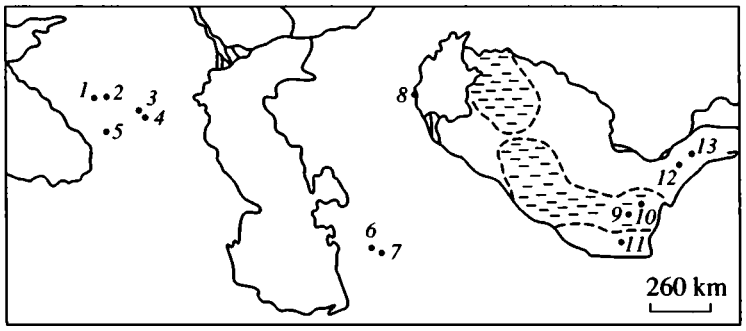

Fig. 1. Location scheme of studied sections with upper Paleocene sapropelite beds: (*1*) Malyi Zelenchuk River, (*2*) Kuban' River, (*3*) Baksan River, (*4*) Kheu River, (*5*) Medani Village, (*6*) Kizil-Cheshme tract, (*7*) Torangly tract, (*8*) Aktumsuk Cape, (*9*) Guru-Fat'ma tract, (*10*) Kurpai tract, (*11*) Ak-Tash Village, (*12*) Isfara River, (*13*) Shor-Su River (distribution area of combustible shales is crosshatched).

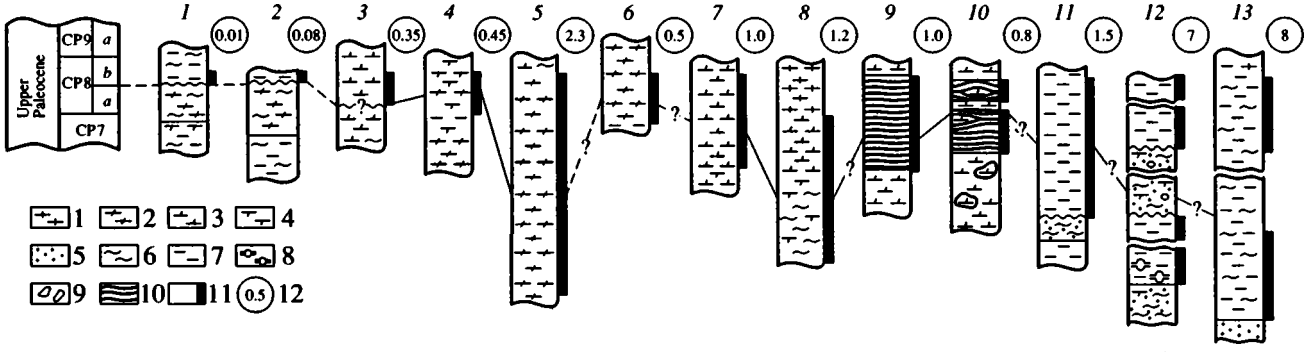

Fig. 2. Lithology of studied sections numbered as in Fig. 1 (vertical scale 0.5 m in 1 cm): (1) limestone, (2) marl, (3) highly calcareous clay and shale, (4) slightly calcareous clay and shale, (5) sandstone, (6) siltstone, (7) carbonate-free clay and argillite, (8) siliceous rocks, (9) pebbles or conglomerate, (10) combustible shale, (11) sapropelite, (12) sapropelite thickness in meters.

In the vast territory of the Amudar'ya–Syrdar'ya interfluve, sapropelite is saturated with organic matter up to the state of combustible shale (Davidzon *et al.*, 1982; Muzylev *et al.*, 1994). We studied these rocks in sections of the Tajik Depression. Geochemical characteristics and some paleontological data on sapropelite from most of the studied sections were published previously (Gavrilov and Muzylev, 1991; Muzylev *et al.*, 1996; Gavrilov *et al.*, 1997). In this paper, we consider foraminiferal paleocoenoses from sapropelite beds and some data on associated calcareous nannoplankton, organic-walled phytoplankton and cyanobacteria.

INVESTIGATION PROCEDURE

Percentages of planktonic and benthic foraminifers, along with proportions of agglutinated and calcareous forms among the latter, may serve as a paleoenvironmental indicator. The calculation procedure was as follows. The washed residue of a sample was mixed up, and its portion containing no less than 200 or 300 tests was used to calculate abundance rates of planktonic and benthic species. Another portion bearing 200 to 300 benthic foraminifers was used to calculate the agglutinated and calcareous forms, and, separately, those, which are able to survive quasi-anoxic environments. The last group includes calcareous benthic foraminifers tolerant to the lowered concentration of dissolved oxygen. These are nonionids, *Lagena, Bulimina*, and *Bolivina* species, all of the infauna type (Kaiho, 1991, 1992, 1994). The results of calculations are shown in Fig. 3. Foraminiferal tests from sapropelite are often small and pyritized, and those of benthic species are corroded in addition. Accordingly, we met difficulties with species identification and detailed comparison of foraminifer assemblages.

ANALYSIS OF FORAMINIFERAL PALEOCOENOSES

Central Ciscaucasia. In the Kheu River section exposing the entire interval of sapropelite bed, a basal part of the latter lacks foraminifers. Planktonic forms are recorded slightly above the base, and few benthic specimens occur higher. The middle portion of lighter color is richer in benthic foraminifers, and they constitute almost 60% of the total foraminiferal tests. Agglutinated and calcareous forms occur in equal proportion at this level. Planktonic forms dominate again in the upper part, where *Morozovella* spp. are abundant and benthic foraminifers represent 20% of the assemblage. As for benthic forms, agglutinated *Hippocrepinella* sp. and calcareous *Lenticulina* sp., *Cancris* sp., and *Bulimina* sp. were encountered throughout the whole interval

of sapropelite bed. The study of washed rock samples selected for foraminiferal analysis showed that pyrite is a common mineral in sediments immediately underlying the sapropelite and near the base of the latter. In the middle of the bed, pyrite content substantially decreases and rises again in the upper portion, where it is though less abundant than in the basal interval. Outcrops along the Malyi Zelenchuk, Kuban', and Baksan rivers exhibit only an upper part of the sapropelite bed that is assigned to the CP8b Subzone. In two former sites, traces of a submarine erosion are clearly noticeable at the base of the sapropelite. In the Baksan River section, distinct erosional features are absent, and hiatus in sedimentation is established by biostratigraphic data suggesting that sediments of the CP8a Subzone are missing here. Studying all three sections, we failed to find analogues of foraminiferal paleocoenosis characterizing the lower part of sapropelite bed exposed in the section of the Kheu River (see Fig. 3).

Western Georgia. In the sapropelite section near the Medani Village, the encountered benthic foraminifers include few, poorly preserved agglutinated *Hippocrepinella* sp., *Marsonella* sp.?, and *Haplophragmoides* sp.? in association with calcareous *Nodosaria* sp., *Lenticulina* sp., *Pullenia* sp., and *Bolivina* sp. Scarce rachislike sponge microscleres of the *Desmospongia* group occur as well. Planktonic foraminifers strongly predominate in sapropelite, especially at higher bed levels, where abundance of *Morozovella* forms also grows. Scarce radiolarians were encountered as well. Tests of planktonic foraminifer are small, slightly increasing in size upward in the section.

Western Kopet-Dag. In sections of the Kizil-Cheshme and Torangly tracts, the lower part of sapropelite bed is barren of foraminifers. In the middle part, there are numerous benthic forms mostly represented by *Lenticulina* sp., less abundant *Bulimina* sp. and other species tolerant to oxygen deficiency. Planktonic taxa dominant at the top associate with few agglutinated forms. In the lower and upper parts of the bed, remains of planktonic foraminifers are represented by internal molds split into separate chambers mainly composed of silica. According to Speijer *et al.* (1997), rocks underlying the sapropelite bed in the Torangly section contain an assemblage with *Gavelinella beccariiformis* (White) and abundant *Nuttallides truempyi* (Nuttall). The lowermost sapropelite interval lacks foraminifers. A rather monotonous assemblage with dominated *Lenticulina* spp. and *Bulimina midwayensis* (Cush. et Parker) occurs above basal level being replaced at the top by a monotypic assemblage of *Stainforthia* sp. Deposits overlying the bed yield a slightly more diverse assemblage dominated by *Lenticulina* spp., *Bulimina callahani* Galloway et Morrey, and *B. midwayensis* (Cush. et Parker). Unfortunately, the precise data on agglutinated foraminifers and planktonic forms have not been considered in the work mentioned above.

Eastern Ustyurt. Two sections with the exposed Thanetian sapropelite beds occur at the Aktumsuk Cape. In the Aktumsuk-1 section, sapropelite is 20 to 25 cm thick, separated 1 m below by the erosional surface from Campanian deposits. In the Aktumsuk-2 section that is about 1.5 km apart, the sapropelite thickness increases up to 1.2 m, and this bed is of three-member structure. In the bed of the latter section, dominant are benthic foraminifers. Agglutinated and calcareous forms occur here in roughly equal proportion. These are mainly rotaloid aerobic forms.[1] In addition, a sharp increase in abundance was recorded in the middle part of the bed for agglutinated benthic forms, and in the upper part for planktonic foraminifers. A similar situation is characteristic of the Aktumsuk-1 section, where plankton is more abundant in the upper part of the bed. Along with foraminifers, the sapropelite yields radiolarians.

The Tajik Depression. In the Guru-Fat'ma and Kurpai sections, the sapropelite is of the combustible shale type. Very small planktonic foraminifers predominate in the bed under discussion. In the upper part of the bed, they associate with calcareous benthic forms (partially dissolved *Lagena* sp., *Lenticulina* sp., and *Bulimina* sp.) and with abundant aerobic species of the rotaloid type. In the central part of the depression (Kafirnigan region), combustible shales contain remains of mollusks, corals, sponges, crinoids, and echinoids (Davidzon *et al.*, 1982).

Southwestern spurs of the Gissar Ridge. Fossils from the sapropelite bed in the section near the Ak-Tash Village are represented by abundant agglutinated benthic foraminifers, few planktonic forms, and radiolarians. According to Davidzon *et al.* (1982), the dark gray clays bearing pyrite concretions, or sapropelite in our interpretation, are attributed in this region to the Kaptar Beds of the Givar Horizon. They yield abundant agglutinated foraminifers, calcareous *Lagena, Robulus*, and *Dentalina* species, and molluscan molds.

The Fergana Depression. Analyzing sections and foraminiferal paleocoenoses of the Isfara and Shor-Su rivers localities, we used, in addition to our records, data of U.M. Rasulov, N.D. Arapova, I.G. Belen'kaya, V.A. Bogomolova, A.R. Kushakov, and N.I. Sakina from the Tashkent University. Unfortunately, They did not estimate abundance rates of foraminifers, and we were unable to plot the corresponding diagrams. The sapropelite bed is of three-member structure in the depression. Numerous holes of decapods are characteristic of top portions of the lower and middle parts of the bed in the Isfara section. Few planktonic foraminifers and radiolarians were encountered only in the lowermost part of the bed. In the Shor-Su section, abundant agglutinated foraminifers are dispersed throughout the sapropelite bed. In the middle part of the bed, we encountered few

[1] We refer to this group the *Gavelinella, Cibicidoides, Anomalinoides, Heterolepa,* and other forms, which often have not been identified at the species level because of a poor preservation.

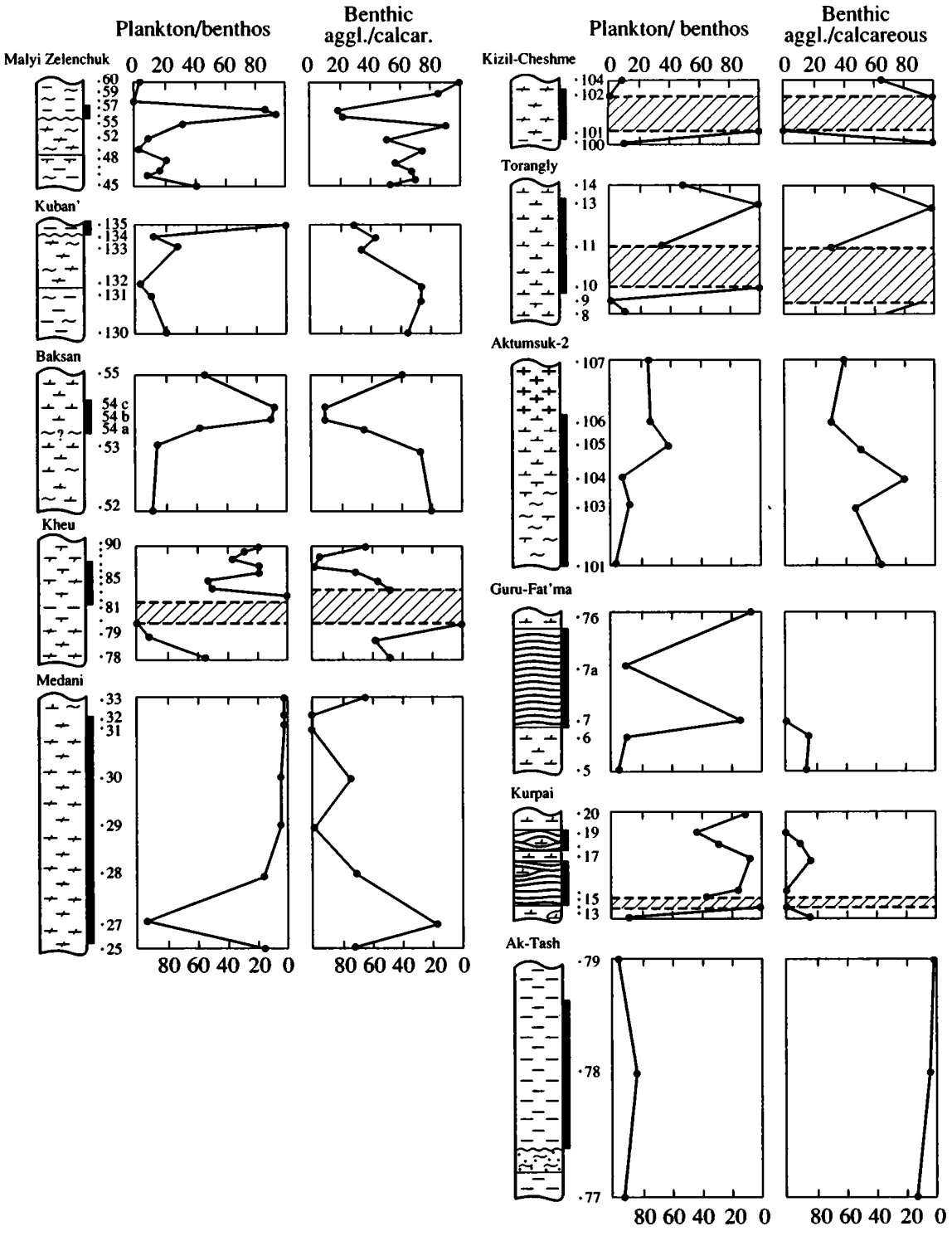

Fig. 3. Diagrams illustrating proportions of planktonic and benthic foraminifers, and agglutinated and calcareous forms among the latter in the sapropelite bed. Intervals barren of foraminifers (section on the Kheu River, sample 81) or of their benthic forms (Kheu River site, samples 82, 83; Kizil-Cheshme site, sample 101; Torangly site, sample 10; Kurpai site, sample 14) are hatched (symbols as in Fig. 2).

planktonic foraminifers, and scarce benthic *Quinqueloculina* sp. with calcareous tests were found in the upper part together with internal molds of benthic ostracodes.

In all studied sections, taxonomic composition and quantitative relationships between groups of benthic foraminifer are similar below and above the sapropelite bed. From our viewpoint, corroded, pyritized and partially dissolved, but not rounded and small foraminiferal tests indicate, together with specific character of benthic paleocoenoses, the autochthonous character of

foraminifer assemblages encountered in the sapropelite bed.

DISCUSSION

In the Late Paleocene, the Eastern Peritethys was likely variably deep in its different areas, but the depth range was evidently moderate and limited by the neritic zone. The Thanetian sediments yield foraminifer assemblages characteristic of the shelf areas. The deepest area were situated in the Ciscaucasia, Transcaucasia, and Kopet-Dag.

As a rule, the sapropelite bed transgressively overlies older deposits. In the sections, where it is of three-member structure, planktonic foraminifers dominate in its lower and upper parts accumulated in the deepest paleobasin areas, because *Morozovella* spp. rather numerous at these levels are inhabitants of relatively deep waters (Boersma and Premoli Silva, 1983, 1991). The proportion of benthic forms increases in the middle part, evidently indicating some shoaling of the basin and a higher water aeration. The appearance of first Paleogene shallow-water nannoplankton species (*Pontosphaera* and *Rhomboaster* forms) is recorded in the middle part as well. In the Malyi Zelenchuk, Kuban', and Baksan sections, the sapropelite bed is represented incompletely, without its lower part. It is possible to suggest that the bed accumulated during two transgressive cycles separated by a regressive phase. The second transgressive cycle was greater, as one can judge from elimination (erosion?) of the sapropelite horizon and from occurrence of commonly numerous "deep-water" *Morozovella* in the sections of central Ciscaucasia and Transcaucasia. Two transgressive events separated by a minor regression within the CP8 Zone are seen in the curve of global sea level oscillations (Haq *et al.*, 1987).

Paleontological and sedimentological analyses shows that the accumulation of the Thanetian sapropelite in the Eastern Peritethys resulted from emergence of quasi-anoxic conditions responsible for a considerable extinction of benthic fauna. Only few eurybiontic forms survived under these conditions. With transition to normal oxygen regime, benthic biota became restored. The oxygen content in the basin varied during the sapropelite accumulation. However, the anoxia and following hydrogen sulfide contamination did not appear, and this is evident from occurrence of benthic fauna of foraminifers, occasional sponges, ostracodes, mollusks, and echinoderms, which populated, though in oppressed state, the studied region. The benthic foraminifers were mainly represented by agglutinated forms having no need in $CaCO_3$ for the shell construction. The calcareous benthic taxa of the quasi-anoxic community were commonly represented by genera tolerant to reduced oxygen concentrations. Few aerobic forms of the rotaloid type were encountered in almost all sections. Their predominance in the eastern Ustyurt and Tajik Depression is an enigma. In some cases, these forms could be attached to floating algae and thus represented pseudoplankton. A similar situation is recorded in the Quaternary sapropel beds of Eastern Mediterranean (Oggioni and Zandini, 1987). In the deepest shelf parts of the paleobasin, i.e. in the Ciscaucasia, Transcaucasia, and Kopet-Dag, the oxygen deficiency was most pronounced. The anoxic conditions may be suggested only for the accumulation time of the basal sapropelite part in the Kheu River, Kizil-Cheshme, and Torangly sections because this level is barren of benthic fauna and pyrite content is high in the Kheu River section. A considerable oxygen deficiency was also characteristic of the combustible shale distribution area in Central Asia, namely, in the Tajik depression (Guru-Fat'ma and Kurpai sections). At the same time, the water aeration was better slightly southward, in southwestern spurs of the Gissar Ridge (Ak-Tash section). In the eastern Ustyurt and Fergana depression, the quasi-anoxic conditions were less pronounced. Gekker *et al.* (1962a, 1962b) noted that calcareous benthic forms from the Fergana depression characterize the shallowest parts of the paleobasin, whereas agglutinated foraminifers only populated its deeper areas, as they sometimes occur together with claws and holes of *Callianassa* and molluscan molds. Some calcareous foraminifers could coexist with agglutinated forms in the paleobasin, but their shells were subsequently dissolved because of the elevated carbon dioxide concentration and low $CaCO_3$ content in the water rich in organic matter.

Gavrilov *et al.* (1997) already discussed possible reasons of organic matter concentration in the upper Paleocene sediments in the south of the former USSR. As noted above, the first occurrence level of shallow-water Paleogene nannoplankton is in the middle of the sapropelite bed. The three-member structure of the bed and the combination of general transgression with the appearance of shallow-water species may indicate the development of the transgression over the area of peneplanation. An intense transgression could result in submergence of a vast, locally swampy land area covered by vegetation of humid subtropical zone (Akhmet'ev and Lebedev, 1994), and, consequently, in the intense inflow of biophile elements in the sea. This, in turn, led to the flourishing of organic-walled phytoplankton that became most likely one of the major contributors of organic matter. Such a flourishing was recognized by Akhmet'ev and Zaporozhets (1996) in the upper Paleocene sapropelites from the Medani and Torangly sections, where sediments yield anomalous mono- or oligodominant assemblages of dinocysts with considerably thickened sheaths. We should emphasize as well that the role of cyanobacteria as contributors of C_{org} is still underestimated. According to Bogolyubova (personal communication) and Muzylev *et al.* (1995), algal-thalline material composed of remains of filiform microorganisms, which are referred to benthic colonial forms resembling *Microcoleus*, strongly dominates in the organic matter of the Thanetian sapropelite (com-

bustible shales) from the Bukhara–Karshi region in the Amudar'ya area. These organisms belong to the group of aerobic oxygen-producing phototrophic cyanobacteria, and their presence in the sediments excludes the anoxic character of environment in the studied part of the basin.

The late Thanetian sapropelite bed is known, in addition to the former USSR, in Jordan (Naji, 1991), Egypt (Speijer and van der Zwaan, 1994; Speijer *et al.*, 1997), New Zealand (Hollis *et al.*, 2000), and Japan (Kaiho, 1988). Its accumulation was most likely associated with the late Paleocene thermal maximum recorded in many regions of the world. Factors responsible for accumulation of deposits enriched in C_{org} and for likely ensuing extinction of bathyal benthic foraminifers at that time are currently under active discussion (*La limite...*, 1998; *Early Paleogene...*, 1999). It is clear nowadays that the sapropelite bed accumulation resulted from global or subglobal events of yet unknown character. Accordingly, the above model of formation of the upper Thanetian sapropelite is most likely applicable only to epicontinental basins of the Eastern Peritethys.

Various paleogeomorphologic, paleohydrologic, and paleogeochemical conditions in the vast territory of the Eastern Peritethys determined different ways of accumulation of sediments enriched in C_{org}. The considerable oxygen deficiency in the water was most probably insufficient for the anoxia. The basin parts corresponding to areas of the Kheu section and western Kopet-Dag at the accumulation time of the sapropelite basal part might represent an exception. We consider the suggested paleogeographic reconstruction only as a possible model of development of quasi-anoxic conditions in the late Paleocene epicontinental basins in the south of the former USSR.

CONCLUSION

(1) In the Late Paleocene, the considered area of the Eastern Peritethys represented an epicontinental basin. Deepest shelf parts of the basin were situated in the Ciscaucasia, Transcaucasia, and Kopet-Dag regions. The sapropelite bed accumulated during two transgressive cycles separated by a relatively short regressive phase. The second transgression was likely greater than the first one.

(2) Sediments rich in C_{org} are commonly, but not always, characterized by predominance of planktonic calcareous microbiota. Anomalous mono- or oligodominant assemblages of dinocysts and cyanobacteria of that microbiota coexisted with oppressed benthic fauna.

(3) Sapropelite accumulated in response to appearance of quasi-anoxic environments. The oxygen deficiency in the paleobasin did not lead however to anoxia and ensuing hydrogen sulfide contamination of water mass. The environments caused a mass extinction of benthos, and only few eurybiontic forms survived. The subsequent transition to a normal regime resulted in restoration of benthic fauna.

(4) In the Eastern Peritethys, sediments became enriched in C_{org} in the course of an intense transgression that led to submergence of a vast swampy coastal plain and to associated inflow of a great amount of biophile elements in the sea. This gave rise to flourishing of organic-walled phytoplankton and cyanobacteria, which produced a mass of organic matter. The available data on the upper Thanetian sapropelites from other regions of the world suggest that their accumulation resulted from some global or subglobal factors.

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REFERENCES

Akhmet'ev, M.A. and Lebedev, E.L., Changes in Climate and Vegetation of Northern Hemisphere in the Late Phanerophyte, *Ekosistemnye perestroiki i evolyutsiya biosfery* (The Ecosystem Changes and the Evolution of the Biosphere), Moscow: Nedra, 1994, no. 1, pp. 278–284.

Akhmet'ev, M.A. and Zaporozhets, N.I., Successions of Dinocysts in the Paleogene and Lower Miocene Sections of the Russian Platform, Crimea-Caucasus Region and Turan Plate as an Indication of Ecosystem Rearrangements, *Iskopaemye organizmy kak osnova stratigrafii, korrelyatsii i paleobiogeografii fanerozoya* (Fossil Organisms as a Basis for Stratigraphy), Moscow: Geos, 1996, pp. 55–69.

Boersma, A. and Premoli Silva, I., Distribution of Paleogene Planktonic Foraminifera—Analogies with the Recent?, *Palaeogeogr., Palaeoclimatol. Palaeoecol.*, 1991, vol. 83, no. 1, pp. 29–48.

Boersma, A. and Premoli Silva, I., Paleocene Planktonic Foraminiferal Biogeography and the Paleooceanography of the Atlantic Ocean, *Micropaleontology*, 1983, vol. 29, no. 4, pp. 355–381.

Davidzon, R.M., Kreidenkov, G.P., and Salibaev, G.Kh., *Stratigrafiya paleogenovykh otlozhenii Tadzhikskoi depressii i sopredel'nykh territorii* (Stratigraphy of Paleogene Deposits in the Tajik Depression), Dushanbe: Donish, 1982.

Early Paleogene Warm Climates and Biosphere Dynamics. Abstract Volume International Meeting. June 9–13, 1999, Göteborg, Sweden. Earth Sciences Centre. Göteborg Univ., 1999, p. 21.

Gavrilov, Yu.O. and Muzylev, N.G., To Geochemistry of Sapropelite Interlayers in the Paleogene Sediments of the Central Caucasus, *Litol. Polezn. Iskop.*, 1991, no. 6, pp. 84–98.

Gavrilov, Yu.O., Kodina, L.A., Lubchenko, I.Yu., and Muzylev, N.G., The Late Paleocene Anoxic Event in Epicon-

tinental Seas of the Peritethys and Formation of Sapropelite Horizon: Sedimentology and Geochemistry, *Litol., Polezn. Iskop.*, 1997, no. 5, pp. 492–517.

Gekker, R.F., Osipova, A.I., and Bel'skaya, T.N., *Ferganskii zaliv paleogenovogo morya Srednei Azii* (The Fergana Gulf of Paleogene Sea in Central Asia), Moscow: Akad. Nauk SSSR, 1962a, vol. 1.

Gekker, R.F., Osipova, A.I., and Bel'skaya, T.N., *Ferganskii zaliv paleogenovogo morya Srednei Azii* (Fergana Gulf of the Paleogene Sea in the Central Asia), Moscow: Akad. Nauk SSSR, 1962b, vol. 2.

Haq, B.U., Hardenbol, J., and Vail, P.R., Chronology of Fluctuating Sea Levels Since the Triassic, *Science*, 1987, no. 4893, pp. 1156–1167.

Hollis, C.J., Field, B.D., Jones, C.M., *et al.*, New Zealand Perspective on Global Change from Late Cretaceous to Early Eocene: (a) the Paleocene–Eocene Transition at Mead Stream, Marlborough, *GFF*, 2000, vol. 122, part 1, pp. 71–72.

Kaiho, K., Uppermost Cretaceous to Paleogene Bathyal Benthic Foraminiferal Biostratigraphy of Japan and New Zealand: Latest Paleocene–Middle Eocene Benthic Foraminiferal Species Turnover, *Rev. Paleobiol.*, 1988, Spec. vol., no. 2, pp. 553–559.

Kaiho, K., Global Changes of Paleogene Aerobic/Anaerobic Benthic Foraminifera and Deep-Sea Circulation, *Palaeogeogr. Palaeoclimatol., Palaeoecol.*, 1991, vol. 83, no. 1, pp. 65–85.

Kaiho, K., Eocene to Quaternary Benthic Foraminifers and Paleobathymetry of the Izu-Bonin Area, Legs 125 and 126, *Proc. Ocean Drill. Progr., Sci. Results*, Taylor, B., Fujioka, K., Janecek, T.R., Langmuir, Ch., Eds., College Station TX: Ocean Drill. Program, 1992, vol. 126, pp. 285–310.

Kaiho, K., Benthic Foraminiferal Dissolved-Oxygen Index and Dissolved-Oxygen Levels in the Modern Ocean, *Geology*, 1994, vol. 22, pp. 719–722.

La limite Paléocéne-Eocene en Europe: évenements et Corrélation, *Strata*, 1998, Ser. 1, vol. 9.

Muzylev, N.G., Anoxic Events of the Paleocene–Middle Eocene Period, *Ekosistemnye perestroiki i evolyutsiya biosfery* (Ecosystem Reorganizations and Evolution of the Biosphere), Moscow: Nedra, 1994, no. 1, pp. 160–166.

Muzylev, N.G., Beniamovskii, V.N., and Tabachnikova, I.P., Sapropelite Interlayers in the Lower Paleogene Sediments of the Southern Soviet Union, *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1989, no. 1, pp. 117–119.

Muzylev, N.G., Beniamovskii, V.N., Gavrilov, O.Yu., *et al.*, Paleontological and Geochemical Characteristics of the Upper Paleocene Sapropel in Central Cis-Caucasus, *Iskopaemye organizmy kak osnova stratigrafii, korrelyatsii i paleobiogeografii fanerozoya* (Fossil Organisms as a Basis of Stratigraphy, Correlation, and Paleobiogeography of the Phanerozoic), Moscow: Geos, 1996, pp. 117–127.

Muzylev, N.G., Nishankhodzhaev, R.N., Rasulov, U.M., *et al.*, The Upper Paleocene Combustible Shales of Central Asia, *Litol. Polezn. Iskop.*, 1994, no. 1, pp. 131–135.

Muzylev, N., Shcherbinina, E., Benjamovsky, V., *et al.*, The Preliminary Data of the Sources of Organic Matter of Upper Tanetian Sapropel Layer of Eastern Peritethys, *IGCP Project 308. Paleocene/Eocene Boundary Events, Beer Sheva, Israel. 8–15 January, 1995, Abst.*, Beer Sheva, 1995, pp. 57–60.

Naji, F., Palaeogene Calcareous Nannoplankton Biostratigraphy of Jordan, *Abstracts of the 4th. INA Conference, Prague*, 1991, vol. 13, no. 2, p. 63.

Oggioni, E. and Zandini, L., Response of Benthic Foraminifera to Stagnant Episodes—a Quantitative Study of Core BAN 81-23, Eastern Mediterranean, *Marine Geology*, 1987, vol. 75, pp. 241–261.

Shutskaya, E.K., *Stratigrafiya, foraminifery i paleogeografiya nizhnego paleogena Kryma, Predkavkaz'ya i zapadnoi chasti Srednei Azii* (Stratigraphy, Foraminifera and Paleogeography of the Lower Paleogene in the Crimea, Ciscaucasia, and Western Central Asia), Moscow: Nedra, 1970.

Speijer, R.P. and Zwaan van der, G.J., The Differential Effect of the P/E Boundary Event on Extinction and Survivorship in Shallow to Deep Water Egyptian Benthic Foraminiferal Assemblages, *Geol. Ultraiectina*, 1994, no. 124, pp. 121–190.

Speijer, R.P., Schmitz, B., and Zwaan van der, G.J., Benthic Foraminiferal Extinction and Repopulation in Response to Latest Paleocene Tethyan Anoxia, *Geology*, 1997, vol. 25, no. 8, pp. 683–686.

Stratigraphy and Geological Correlation, Vol. 9, No. 5, 2001, pp. 508–522. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 9, No. 5, 2001, pp. 94–108.
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The Tarkhanian–Karaganian Stage in Development of the Euxinian–Caspian Basin (Eastern Paratethys). Part 1: Tarkhanian

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Abstract—Evolution of the Euxinian–Caspian basin (Eastern Paratethys since the Oligocene) during the Tarkhanian (terminal early–initial middle Miocene) is considered, and its interrelations with the Alpine–Carpathian (Western Paratethys), Central Iranian, and East Mediterranean basins are discussed. The article includes the map of current distribution of Chokrakian deposits and their continental analogues, and the paleogeographic map for the Chokrakian time, where geological history of the Transcaspian region, Paleo-Don delta area, and Caucasus region are anew interpreted. Supplementary palinspastic profiles illustrate the peculiar morphology and bathymetry of the Chokrakian basin.

Key words: Eastern Paratethys, Tarkhanian, Chokrakian, Karaganian, paleogeography, paleobathymetry, biota evolution, transgression, regression.

INTRODUCTION

The Euxinian–Caspian basin represented a structure inherited from of the West Black Sea and Greater Caucasus back-arc basins, which were located in the northern Tethyan margin, being separated by the underwater Andrusov swell. The back-arc basin of the Greater Caucasus appeared at the beginning of the Jurassic in the area that corresponds to the southern slope of modern orogenic structure and extends from western spurs of the Kopetdag to Crimea. At the Cretaceous–Paleogene boundary time, it significantly grew in size owing to submergence of northern part of the island arc that bounded the basin in the south and in response to formation of the Eastern Black Sea–Trialeti and Fore-Talysh deep-sea depressions. These depressions were separated from the axial Lazarevskoe–Kobystan trough by the Schatsky and Kyurdamir swells. The second half of the Paleogene corresponds to the early collision stage in development of the Greater Caucasus part of the basin (Kopp and Shcherba, 1998). Beginning from the terminal Eocene, the area along the boundary between the African–Arabian continental block and Eurasia was a formation site of land barriers and shallow epicontinental (shelf) seas, which separated the Euxinian–Caspian basin from the suboceanic Mediterranean and Indo-Pacific segments of the Tethys, although connection between them along the peri-Adriatic suture lasted till the middle Miocene (Adams *et al.*, 1983). The intracontinental basin that originated in response to this collision flooded the Eurasian shelf of the Jurassic–Paleogene back-arc sea of the Greater Caucasus with its deep and island-arc segments and the deep West Black Sea depression. In the initial Oligocene, this basin became a part of the Paratethys (the term by Laskarev, 1924), namely its eastern segment (Eastern Paratethys) (Baldi; 1980). Following previous researchers, we consider the Alpine–Carpathian basin of that time as the Western Paratethys. The middle Miocene was a time of transition from the early collision stage in development of the Euxinian–Caspian (Eastern Paratethys) basin to the orogenic one. The initial middle Miocene (Chokrakian) corresponds to the most active phase of this transition, when dimensions of deep-sea troughs were substantially reduced and some of them (southern) were filled with sediments. This phase was also marked by appearance of large land areas in the axial part of the basin and adjacent shelves, which occupied areas of the modern northern slope and central segment of the Greater Caucasus.

The tectonic evolution, climatic oscillations, and sea-level fluctuations changed the basin configuration, opened or closed straits connecting it with adjacent seas, and determined cyclic patterns of the basin development, i.e., the alternation of marine, semimarine, and brackish-water environments that was noted by Andrusov (1961, 1963, 1964) as long ago as in the 1880s.This cyclic development was studied later on by paleontologists, e.g., by researchers from the Laboratory of Paleoecology of Marine Faunas of the Paleontological Institute RAS. It was established that every

cycle included the initial stage marked by transgression that gave rise to normal marine environments and the terminal regression stage that changed the hydrological regime of the basin converting it into semimarine or brackish-water one. The final isolation of the basin from neighboring seas strongly influenced composition and structure of its biota.

Tarkhanian–Karaganian sediments are widespread in southeastern Eurasia (Fig. 1). The Tarkhanian–Karaganian stage differed from all subsequent Miocene cycles of the Eastern Paratethys development owing to a longer existence of normal marine environments terminated by semimarine ones in the last third of the cycle. Paleontological and lithological aspects of this stage are sufficiently well studied, especially the composition and distribution of mollusks and benthic foraminifers. The problem of provenance of the terrigenous material and its transport in the Caucasian region is also thoroughly studied. Main features of bathymetric zoning of the Greater Caucasus basin and its Cenozoic evolution were considered by Kopp and Shcherba (1985, 1998) and by Shcherba (1993) who analyzed them using modern sedimentological data from marginal seas, though without publication of structural maps of the basin for the Tarkhanian–Chokrakian–Karaganian period. The attention was mostly paid to Chokrakian deposits because of their oil-and-gas potential. Different paleogeographic and lithological–facies maps were compiled for this period (Zhizhchenko, 1940, Sorochan, 1958; *Atlas...*, 1962; Pol'ster and Kravchenko, 1964; *Atlas...SSSR*, 1967; Kunitskaya *et al.*, 1969; Sholokhov, 1969; Hamor, 1988; Goncharova, 1989). Maps that were compiled in the 1960s do not reflect new observation results and contemporary ideas.

Map and profile presented here (Figs. 2, 3) are based on the synthesis of paleontological (faunal and floral), lithological, and structural data. This is a current attempt to get insight into dynamic biogeography of the Northern Peritethys and continuation of paleogeographic research by scientists from the Paleontological and Geological institutes who worked on the problem in the last period. Unlike the above-mentioned maps, the presented one includes not only the entire Eastern Paratethys and its northern and southern shelves of the continental framing, but some epicontinental seas of the Southern Peritethys as well. Contribution of many specialists to lithological–paleogeographic maps of Eurasia (Institute of Tectonics of Lithosphere Plates, the Russian Academy of Natural Sciences) and Peritethys (International Peritethys Research Program) reveals more adequately the significance of the considered stage in the Mesozoic evolution of the northern and southern margins of the Tethys, and of the entire Peritethys. In this paper, we consider evolution, morphology, hydrology, and biota of the Euxinian–Caspian basin during the Tarkhanian, Chokrakian, and, to a lesser extent, the Karaganian periods.

STRATIGRAPHY AND CORRELATION OF TARKHANIAN, CHOKRAKIAN, AND KARAGANIAN

Similarly to other Neogene stratigraphic units, the Tarkhanian, Chokrakian, and Karaganian regional stages of the Pontian–Caspian region were defined as horizons by N.I. Andrusov at the boundary time of the 19th and 20th centuries based on changes in molluscan assemblages. He was first to propose the Neogene stratigraphic scheme for the southern areas of the former USSR. In subsequent works of M.V. Bayarunas, L.Sh. Davitashvili, B.P. Zhizhchenko, A.K. Bogdanovich, E.V. Liverovskaya, R.L. Merklin, K.G. Bagdasaryan, G.A. Kvaliashvili, M.F. Nosovskii, and others, paleontological characteristics of these horizons and their stratigraphic ranges were understood more adequately. In the regional scale of the Eastern Paratethys approved by the Interdepartmental Stratigraphic Committee of the USSR in 1983, the horizons defined by Andrusov acquired the rank of regional stages.

Scopes of the Tarkhanian and Chokrakian are still debatable. Main discrepancies in opinions concern the age of transitional sequence of the so-called *Spirialis* Clays (Argun Beds; Table). The latter are usually referred, partially (Zhizhchenko, 1940; Konenkova and Bogdanovich, 1994, Ananiashvili, 1999) or entirely (Zhizhchenko, 1959; Bagdasaryan, 1965, 1970), to the Chokrakian. Following Merklin (1950), Nosovskii (1976, 1998), and Andreeva-Grigorovich and Savytskaya (2000), we include them entirely into the Tarkhanian because the terminal period of accumulation of the Argun Beds was marked, in additional to faunal changes, by structural and sedimentological reorganizations (Goncharova, 1989).

In line with this standpoint, the Tarkhanian regional stage is subdivided into the lower (Kuvinskii Beds), middle (Terek Beds), and upper (Argun Beds) substages. Shallow-water facies of the lower Tarkhanian Substage enclose oyster species *Crassostrea gryphoides*, whereas its deeper facies contain rare species marine mollusks *Nucula nucleus, Aporrhais pespelecani*, and *Lunatia helicina*. Simultaneously, both facies host brackish-water relic *Rzhehakia dubiosa* (= *R. socialia* Rz.), and lagoonal facies yield the Kotsakhurian relic *Congeria nucleoulus* Rzehak. The middle Tarkhanian Substage, frequently termed also as the "Tarkhanian Marl" or beds with *Lentipecten corneus denudatus*, corresponds to the *Quinqueloculina boueana* Zone of benthic foraminifers (Bogdanovich, 1965, 1974), characteristic mollusks of which are *Lentipecten corneus denudatus* (Reuss), *Nucula nucleus* (L.), *Neopycnodonte navicularis* (Brocchi), *Aporrhais pespelecani* (L.), and *Lunatia helicina* (Brocchi). The upper Tarkhanian, correlated in earlier works with a part or entire sequence of *Spirialis* Clays, corresponds to the *Sigmoilina haidingeri* and overlying *Bolivina tarchanensis* zones of benthic foraminifers and contains abundant pteropod mollusks *Limacina* (= *Spira-*

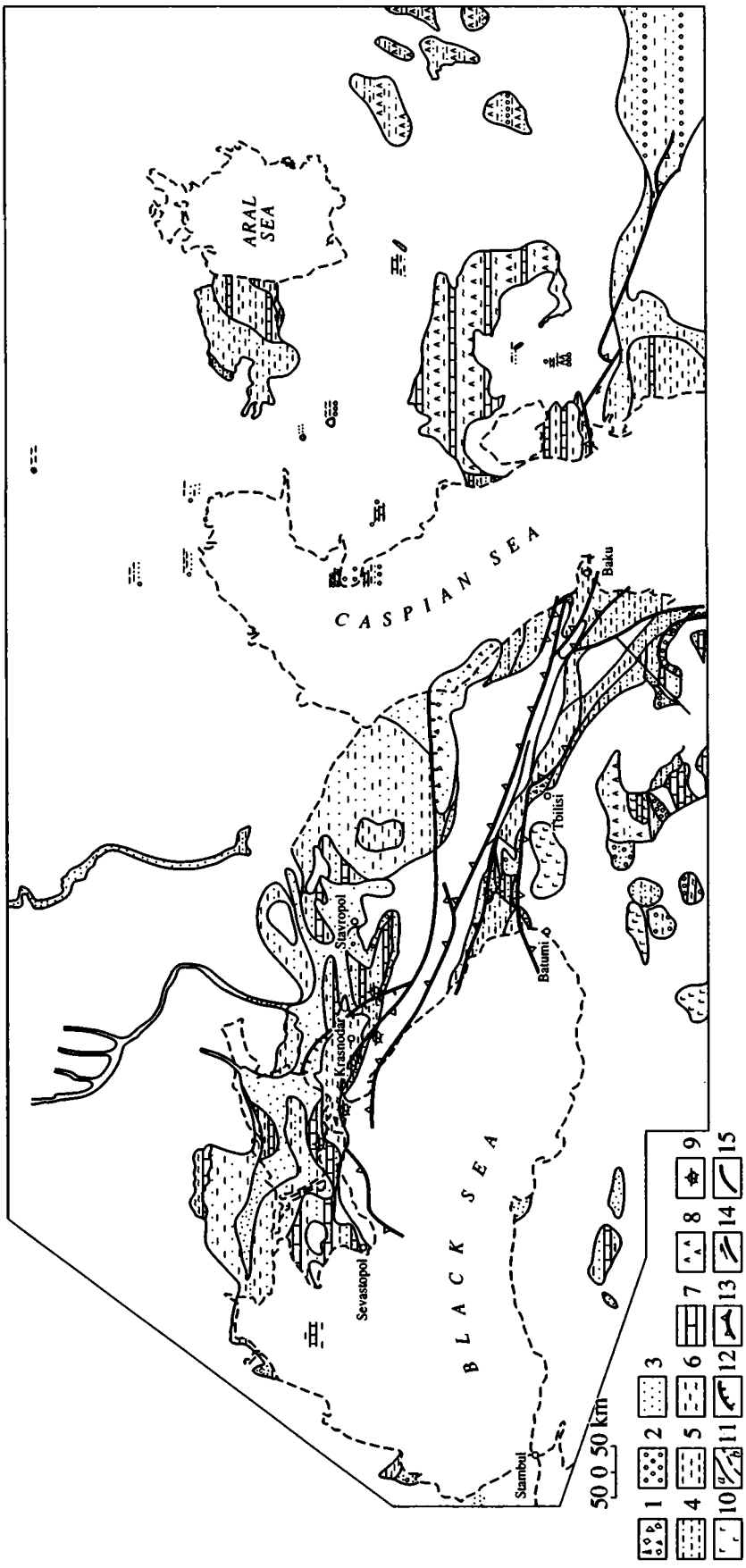

Fig. 1. Map of modern distribution of Chokrakian marine sediments and their terrestrial analogues (compiled by I.A. Goncharova, S.O. Khondkarian, and I.G. Shcherba): (1) breccia; (2) conglomerate; (3) sand and sandstone; (4) silt and siltstone; (5) clay; (6) marl; (7) limestone; (8) gypsum and anhydrite; (9) bioherms; (10) mafic volcanics; (11) boundaries of modern distribution of Chokrakian sediments: (a) proven, (b) inferred; (12) faults; (13) thrusts; (14) strike-slip faults; (15) other faults.

tella). Characteristic middle Tarkhanian mollusks, as well as nodosariids and textulariids, occur only in some basal upper Tarkhanian layers.

The Chokrakian regional stage is subdivided in the lower and upper substages (or Zyuk and Bryk beds, respectively). The lower Chokrakian layers are traceable virtually throughout the entire Eastern Paratethys from Bulgaria to Kopetdag, as they correspond to the *Tschokrakella caucasica* Zone of endemic foraminifers and yield specific Chokrakian molluscan species *Aquipecten varnensis* (Toula), *Ervilia praepodolica* Andrus., *Angulus* (*Fabulina*) *fuchsi* (Toula), *Donax tarchanensis* Bajar., *Pitar laskarevi* (Schwets), and *Cerithium cattleyae* Baily. The upper Chokrakian corresponds to the *Nonion parvus* Zone of benthic foraminifers and yields six molluscan species, most abundant of which are *Ervilia praepodolica* Andrus., *Donax tarchanensis* Bajar., and *Lutetia intermedia* (Bajar.) (*Neogenovaya systema*, 1986b; Goncharova, 1989).

The Karaganian regional stage is subdivided into three subunits: lower substage (Arkhashen or *Spaniodontella* Beds) showing prevalence of endemic molluscan species *Spaniodeontella gentilis*; middle substage (Varna Beds) enclosing, in addition to *Spaniodontella* representatives, endemic *Savanella* forms and rare marine mollusks; and upper substage (Pholad or Kartveli Beds) whose belonging to the Karaganian regional stage was long debated (*Neogenovaya systema*, 1986a). In this paper, the Karaganian regional stage with its Varna Beds reflecting short-time transgression is considered briefly.

Correlation of the Tarkhanian and Chokrakian with the Mediterranean scale is controversial. This is partly connected with the unfortunate selection of the Langhian stratotype that led to the ambiguous interpretation of the interval in question and lower–middle Miocene boundary by different researchers (for discussion see Krasheninnnikov *et al.*, 1999). The initial interpretation of the lower boundary of the Karpatian and Badenian regional stages in the Western Paratethys is also ambiguous, because it is correlated with the first occurrence of either *Praeorbulina* (Badenian; Chicha *et al.*, 1975a) or *Orbulina* (Karpatian; Chicha *et al.*, 1975b) representatives. There are also some other problems. For instance, based on nannoplankton assemblages, the Tarkhanian is correlated either with the uppermost NN4–basal NN5 Zone (Konenkova and Bogdanovich, 1994; Ivanova *et al.*, 1998; Rögl, 1998) or only with the basal part of the NN5 Zone (Andreeva-Grigorovich and Savytskaya, 2000). Interpretation of paleomagnetic data is also contradictory, probably owing to different understanding of the scope of the Tarkhanian. M.A. Pevzner (Steininger *et al.*, 1987, p. 417) considers the base of the Tarkhanian as corresponding to the uppermost magnetic Zone 17 and correlates the middle–lower upper Tarkhanian with the Chron C5Cn1n of the Berggren's scale (Berggren *et al.*, 1995). In his opinion, the entire Tarkhanian–Chokrakian interval extends from the base of the Chron C5Cn1n to the basal part of the Chron C5ADn (16.3–14.2 Ma). E.A. Molostovskii (Molostovskii and Khramov, 1997) correlates the Tarkhanian with an upper part of the reversed magnetic polarity epoch 16 (i.e., with the upper two thirds of the Chron C5Br), placing the coupled Tarkhanian–Chokrakian interval between the base of the Chron C5Br and uppermost Chron C5ADn (15.7–14.2 Ma). According to Trubikhin (1998), the Tarkhanian–Chokrakian spans interval from the top of Chron C5Cn and to the base of Chron C5Ar (16–13 Ma). The presence of *Tuberculodinum vancampoae* (the index species of the lower Miocene Subzone VIIb in the dinocyst zonation proposed by Da Costa and Downie, 1979), *Hystrichosphaeropsis obscura*, and *Lingulodinium machaerophorus* in the basal part of the upper Tarkhanian (Zaporozhets, 1999) suggest that the greater part of the Tarkhanian can be correlated with the Karpatian and upper Burdigalian. This conclusion concurs with data by Ivanova (Ivanova, 1999; Ivanova *et al.*, 1998) who discovered the planktonic foraminiferal assemblage of the lower Miocene *Globigerinitella insueta* Zone in basal upper Tarkhanian (Argun Beds) of the Crimean Plain. Her data can be supported by correlation with coeval subdivisions in the Western Paratethys (Table): Kotsakhurian with Ottnangian and Karpatian with the basal Tarkhanian, that is based on endemic mollusks (Goncharova, 1991; Studencka *et al.*, 1998)[1].

Correlation of the Chokrakian with the basal part of the NN5 nannoplankton zone (Konenkova and Bogdanovich, 1994), as well as its position between the Tarkhanian (partly correlative with the Karpatian) and Karaganian (correlative with the Velichkian) allows this regional stage to be correlated with the Langhian in the Mediterranean scale and with the lower Badenian (Moravian) of the Western Paratethys. There is a contradiction between data on diatoms and mammals. *Coscinodiscus grunowii* Pant. and *Coscinodiscus* (=*Cestodiscus*; Radionova, 1991) *stokesianus* Grew. present in the Chokrakian diatom assemblage of northeastern Bulgaria indicate its similarity with the lower Miocene (Karpatian) assemblage of *Raphidodiscus marylandicus* Zone, on the one hand, and with the lower Badenian assemblage, on the other (Temnikova-Topalova and Kozyrenko, 1982). In the Belomechetka area (Central Ciscaucasia), the uppermost lower Chokrakian bearing mammal fossils corresponds either to the MN5 Zone by

[1] Endemics attract special attention, because general similarity levels of bivalves from different basins are ambiguous. The Jaccard coefficients (the share of species in common in two basins relative to their total diversity) turned out to be similar: 13% for the Tarkhanian, Karpatian, and Badenian, 9% for the Chokrakian and Karpatian, and 19% for the Chokrakian and Badenian. The similarity index between the Eastern and Western Paratethys during the Tarkhanian (13%) is higher than during the Chokrakian (9–10%), and it is likely that the exchange between these basins became probably restricted, while, as will be shown below, the exchange between the Eastern Paratethys and Tethys simultaneously increased.

Mane (Gabuniya and Bendukidze, 1984), or to the MN6 Zone (*Neogenovaya sistema*, 1986b).

According to occurrence of evaporites, the Karaganian is usually correlated with the middle Badenian (Velichkian), and this is supported by its correlation with the NN5 nannoplankton zone (data by E.M. Bogdanovich, in Barg, 1993, p. 125). The endemic Karaganian fauna lacking zonal species make its correlation with the Mediterranean scale even more difficult than in case of the Tarkhanian and Chokrakian. Taking into consideration the inferable correlation of the latter with the standard Mediterranean stages, the Karaganian should be probably correlated with the upper Langhian–basal Serravalian.

CLIMATE

According to Akhmet'ev (1993), the Tarkhanian corresponds to the second Neogene climatic optimum. Fact confirming this conclusion are as follows: presence of thermophilic molluscan genera *Pteria, Perna, Isognomon, Atrina, Limaria, Chama, Gibbula, Turritella*, and *Calyptraea* (Goncharova, 1989; Il'ina, 1993); remains of mesophilic subtropical flora (Purtseladze, 1983; Burova and Panova, 1998) and nannoplankton (Andreeva-Grigorovich and Savytskaya, 2000); occurrence of sargasso algae, lunulitiform bryozoans (oral communication by L.A. Viskova), and thermophilic ichthyofauna (*Neogenovaya sistema*, 1986b); the known insect assemblage of termites, cockroaches, and ants that includes the thermophilic genus *Dolichoderus* Lund. (Zherikhin *et al.*, in Goncharova, 1989).

Thermophilic molluscan genera *Pteria, Perna, Isognomon, Limaria, Chama, Alaba*, and *Obtortio* (Goncharova, 1989; Il'ina, 1993), abundant thermophilic bryozoan genus *Cellaria* (Veis, 1988), mesophilic subtropical flora with *Sapindus, Cinnamomum, Laurus, Myrica*, and *Carya* (Grossgeim and Gladkova, 1950; Ramishvili, 1983; Akhmet'ev, 1995), plant remains typical of mangrove thickets discovered near one of the East Caucasian islands (Chechnya, Fortanga River; Akhmet'ev, 1995), and composition of the entomofauna (cycads, ants, termites; Grossgeim and Gladkova, 1950; Bekker-Migdisova, 1964; Dlusskii, 1981) indicate that conditions of the second Neogene climatic optimum were also characteristic of the subsequent Chokrakian period. The climate of the Tarkhanian and early Chokrakian was probably similar to the modern subtropical one (Zhizhchenko, 1940; Grossgeim and Gladkova, 1950; Akhmet'ev, 1993; Burova and Panova, 1998). During the Chokrakian, climate was more arid in the Transcaspian region, where evaporites and red-colored sediments are developed, and in Azerbaijan as well (Akhmet'ev, 1993).

Climate of the Karaganian time was probably as warm as in the Chokrakian, although, as one can judge from floral (Mchedlishvili, 1951) and lithological (Belokrys, 1984) data, it was drier, especially during summer seasons (Akhmet'ev, personal communication). Similar conditions existed also in the Western Paratethys during the Velichkian period (Syabrai and Teslenko, 1999). It is not inconceivable that the seasonal aridity appeared as early as in late Chokrakian.

PALEOBATHYMETRIC ZONING IN THE EASTERN PARATETHYS DURING THE TARKHANIAN, CHOKRAKIAN, AND KARAGANIAN

Despite its significant isolation from the ocean (inland position), the Euxinian–Caspian basin preserved until the mid-Sarmatian time the paleobathymetric zoning of the back-arc sea that was established at the beginning of the Paleogene (Kopp and Shcherba, 1998). Simultaneously, troughs and rises in the bottom topography of the initial Paleogene basin significantly

Fig. 2. The paleogeographic map of the Eastern Paratethys for the Chokrakian time with basin contours corresponding to its maximum dimensions in this period (compiled by I.A. Goncharova, S.O. Khondkarian, and I.G. Shcherba using data from *Atlas paleogeograficheskikh...*, 1960; *Atlas ... obramleniya*, 1962; *Atlas ... SSSR*, 1967; *Neogenovaya sistema*, 1988; *Neogene Paleogheographic...*, 1988; *Paleogeographic atlas...*, 1997, and investigation results by V.I. Gusev, B.P. Zhizhchenko, A.S. Zastrozhnov, Yu.I. Iosifova, M.S. Karasev, V.N. Kravchuk, E.I. Koyumgieva, V.G. Kulichenko, V.N. Krymus, B.I. Pinkhasov, T.N. Pinchuk, B. Strashimirov, D.A. Tugolesov, V.V. Sholokhov, and Yu.G. Chel'tsov).

Land: (1–4) accumulative plains: (1) gray-colored limnetic–alluvial sediments, (2) red-colored sediments, and (3) molasses of accumulative plains; (4) plains with eroded sedimentary cover or initially barren of the latter; (5) rises; (6) mountains. **Sea:** (7) deep areas; (8) mostly sandy (a) and clayey–calcareous (b) deposits of deep shelf; (9) different sandy facies (a) and clayey–calcareous sediments (b) shallow shelf; (10) lagoons; (11) avandelta; (12) hyperhaline setting; (13) alternating marine and terrestrial settings; (14) bioherms; (15) olistostromes; (16) terrestrial volcanism (mafic volcanics); (17) sedimentary clinoforms (in profiles); (18) plant remains; (19) bone remains; (20) main transport directions of detrital material; (21) proven (a) and inferred (b) paleogeographic and lithological–facies boundaries; (22) extreme boundary of sea basin; (23) normal faults, flexures; (24) syndepositional (a) and postdepositional thrusts (b); (25) strike-slip faults; (26) other faults; (27) lines of palinspastic profiles I–I and II–II; (28) isopachs (a) and thickness of Chokrakian sediments at particular points (b).

Structural elements of Euxinian–Caspian basin indicated by encircled numbers. **Axial area:** (1) deep Kobystan–South Caspian depression; (2) Guriya, (3) Adzhariya, and (4) Fore-Talysh depressions uplifted to the level of the deep shelf by the end of the early Chokrakian. **Southern shelf:** (5) Iori–Kura, (6) Novorossiisk, and (7) Shemakha depressions; (8) Andrusov, (9) Schatsky, and (10) Kyurdamir swells. **Northern shelf:** (11) West Kuban' and (12) Terek–Caspian depressions, (13) relic of the Kuma depression; (14) island of Greater Caucasus and Laba–Stavropol rise (14a); (15) East Caucasian archipelago. **Iranian–Lesser Caucasian collision belt:** (16) South Armenia gulf of the Central Iranian basin; (17) Sevan–Aragats lagoon; (18) Middle Araks strait; (19) Central Iranian basin; (20) South Van strait; (21) Aleppo–Urfin strait; (22) Mesopotamian basin; (23) Mediterranean Sea.

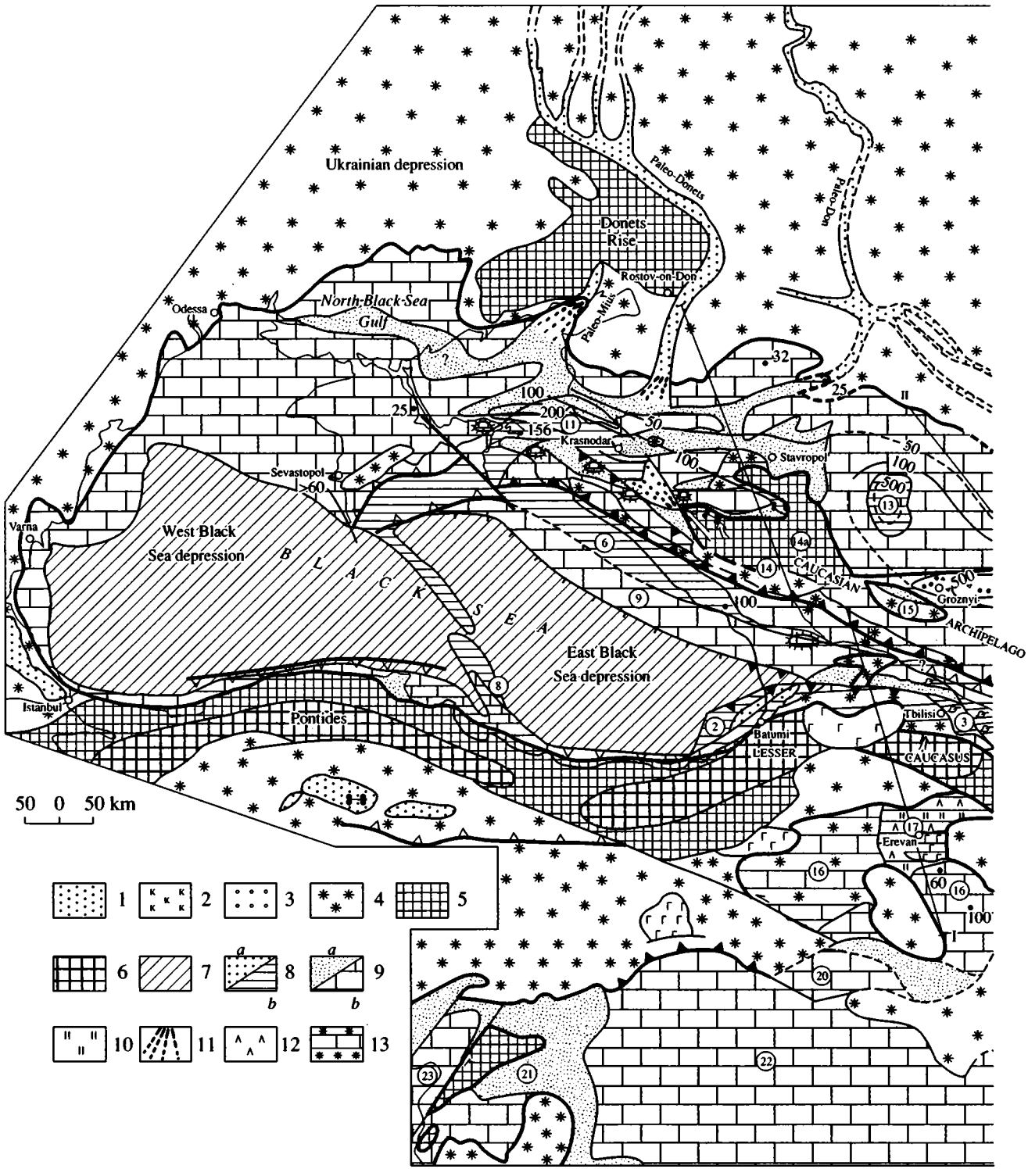
Ukrainian depression
Donets Rise
Paleo-Donets
Paleo-Don
Rostov-on-Don
Paleo-Mius
North Black Sea Gulf
Odessa
Krasnodar
Stavropol
Sevastopol
Varna
West Black Sea depression
BLACK SEA
East Black Sea depression
Pontides
Istanbul
Batumi
LESSER CAUCASUS
GREATER CAUCASIAN
Grozny
ARCHIPELAGO
Tbilisi
Erevan
50 0 50 km
1
2
3
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Fig. 2.

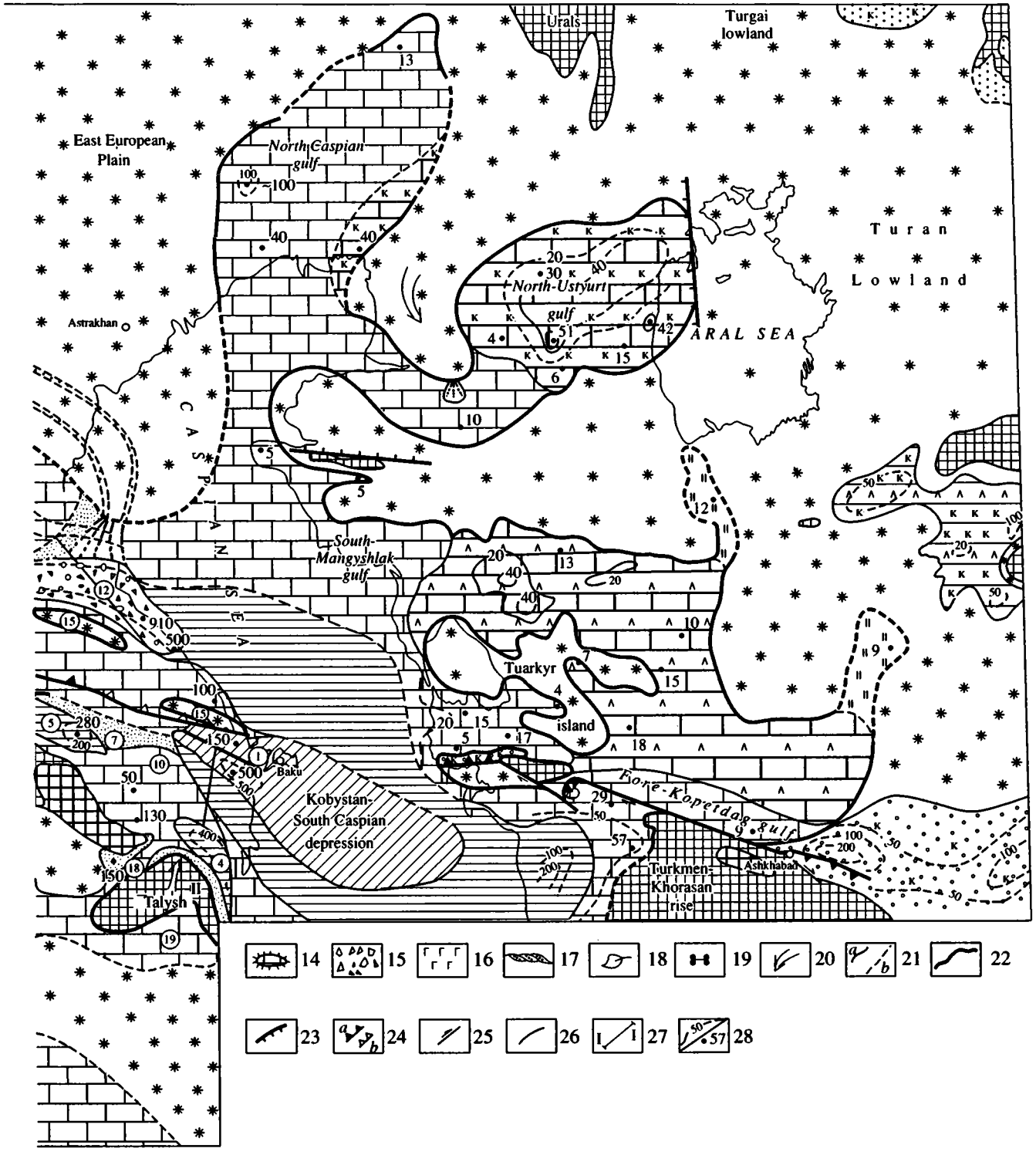

Urals
Turgai lowland
East European Plain
North Caspian gulf
Turan Lowland
North-Ustyurt gulf
ARAL SEA
Astrakhan
CASPIAN SEA
South-Mangyshlak gulf
Tuarkyr island
Kobystan-South Caspian depression
Baku
Bore-Kopetdag gulf
Turkmen-Khorasan rise
Ashkhabad
Talysh
14 15 16 17 18 19 20 21 22
23 24 25 26 27 28

Fig. 2. (Contd.)

changed their configuration and dimensions in the course of collision. Continental environments prevailed on the southern, formerly island-arc margin of the basin at that time. The following topographic elements can be distinguished in the structure of the considered region (Figs. 2, 3).

(1) The northern, Eurasian shelf of the Eastern Paratethys included the North Caucasus, greater part of the Kopetdag, Crimea, Scythian and Turan plates, and areas of East European platform around the Black Sea.

(2) The axial part of the Eastern Paratethys (Fig. 2) comprised the Kobystan–South Caspian (Fig. 2, 3: 1), East Black Sea–Trialeti, and West Black Sea deep-sea depressions. The Kobystan–South Caspian depression (with the Lazarevskoe–Kobystan trough in the axial part) represented a relic of the Mesozoic back-arc sea of the Greater Caucasus that geographically corresponded to the modern southern slope of the Caucasian orogen. During the considered period, the deep-sea settings in the northwestern Caucasus, which existed there prior to the initial Miocene, disappeared. The East Black Sea–Trialeti basin, a relic of the vast Adzhariya–Trialeti inter-arc trough of the Paleogene time, was reduced in the east and included only the extreme northwestern part of the trough. The West Black Sea depression that developed in the Mesozoic independently from the Greater Caucasus marginal sea was separated from the East Black Sea basin by the Andrusov swell (Fig. 2: 8) being localized within the modern Black Sea boundaries. Shelf areas separating these basins joined the northern shelf of the Eastern Paratethys. The shelf zone also included the underwater Kyurdamir (Fig. 2: 10) and Schatsky (Fig. 2: 9) swells that complicated the Mesozoic island-arc structure in the Paleogene.

(3) The orogenic belt that included the Lesser Caucasus mountains (Somkhet–Agdam uplift of the Paleogene time in the southern part of the Mesozoic island arc), Pontides, Talysh, Elburz, and southern uplifts of the Turkmen–Khorasan folded area represented the southern framing of the Euxinian–Caspian basin. In the north, this belt was bounded by a narrow band of shallow southern shelf of the Eastern Paratethys with separate deep-sea areas (Iori–Kura depression; Fig. 2: 5). The area located south of the belt was occupied by the South Armenia gulf (Fig. 2: 16) of the Central Iranian shallow basin (a part of the Tethyan shelf) that intruded the Central Anatolia land.

EVOLUTION OF THE EASTERN PARATETHYS DURING THE TARKHANIAN, CHOKRAKIAN, AND KARAGANIAN

By the end of the Kotsakhurian (the latest early Miocene), the Eastern Paratethys was significantly reduced in dimensions, became shallower, and turned into the shelf basin with the flattened bottom. Conceivably, its inner part located within the modern North Caucasus was partly dried, as it is indicated by the pre-

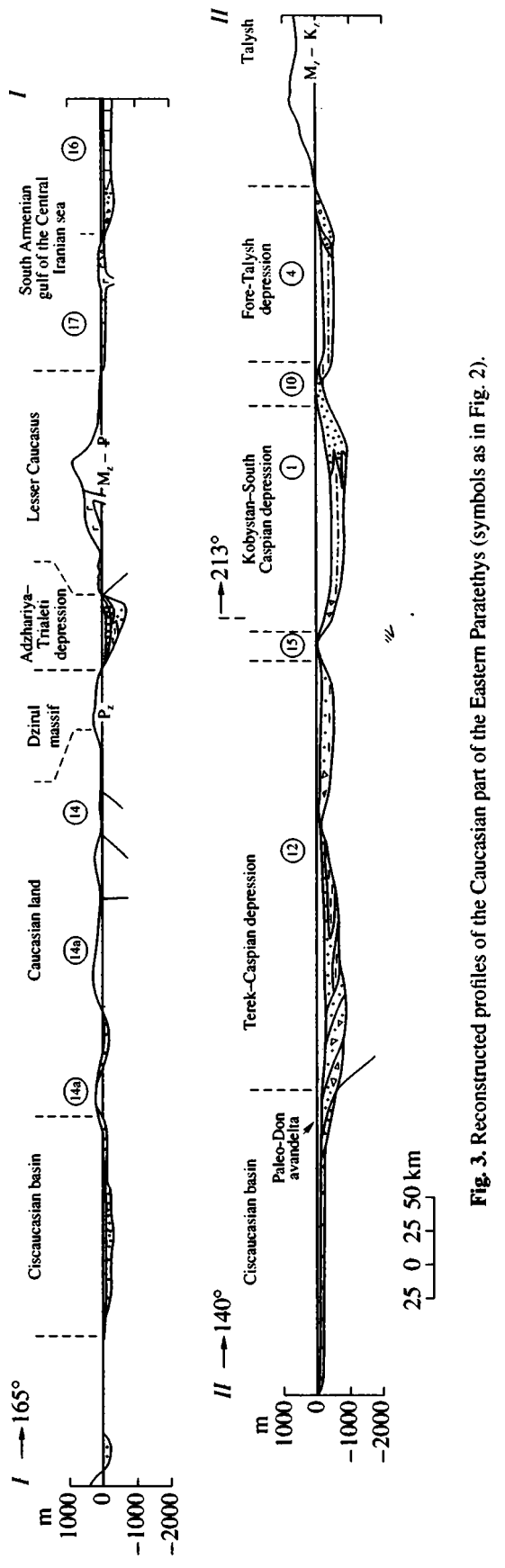


Fig. 3. Reconstructed profiles of the Caucasian part of the Eastern Paratethys (symbols as in Fig. 2).

Tarkhanian hiatus recorded in the East Caucasian sections (Milanovskii and Khain, 1963).

In response to transgression and breakthrough of sea waters at the beginning of the Tarkhanian, the hydrogen sulfide contamination mainly disappeared from the basin that began to accumulate clayey–calcareous sediments characteristic of normal marine settings. The exception were the pseudoabyssal areas of the Kerch–Taman' periclinal depression of the northwestern Caucasus, West Kuban' (Fig. 2: 11) and Terek–Caspian (Fig. 2: 12) depressions of the Ciscaucasia, and also the Kobystan–South Caspian trough (Fig. 2: 1) of the deep-sea basin of the southeastern Caucasus (Alizade *et al.*, 1980, pp. 68, 69). The term *pseudoabyss* was introduced by Andrusov (1961) in 1897 and applied by Zhizhchenko (1940) to characterize deep-sea areas of the Tarkhanian and Chokrakian basins. It is accepted here (following Deryugin, 1915) as designating the lowest bathymetric zone in epicontinental basins that begins from the base of the continental slope located well below the sublittoral zone (the distribution zone of macrophitic algae 100–150 m deep). Fauna of the pseudoabyssal zone includes usually sublittoral forms and has little in common with the oceanic one.

The early Tarkhanian, as well as the beginning of every subsequent cycle, was a period of faunal exchange with the Western Paratethys. Fauna migrated via the Dniester (northwestern) strait that connected the northern Black Sea region and southern part of the Dniester–Prut interfluve (Goncharova, 1989) of the Eastern Paratethys with the Volyn'–Podolia region (Stryp, Koropets, and Zolotaya Lipa rivers, left tributaries of the Dniester River; *Neogenovaya sistema*, 1986a) and Ustichkivskii graben (Prisyazhnyuk *et al.*, 1997) of the Western Paratethys. There were probably other seaways for the interchange between the Tarkhanian and Karpatian faunas. For instance, fauna of the extreme western part of the Tarkhanian basin (southeastern Dobruja, Karapelit Formation of northeastern Bulgaria; Nicolov, 1996) includes five bivalve species *Aequipecten macrotis* (Sow.), *Irus* (Irus) *irus* (L.), *Lithophaga* (Lithophaga) *lithophaga* (L.), *Cardiocardita diversicosta* (Reuss), and *Carditamera* (*Carditamera*) *auingeri* (Hoernes), which are missing from other areas of the basin. At least, the first three of these species dwelt in the Western Paratethys during the Karpatian. This fact likely indicates penetration of these species into the Tarkhanian basin through the southern Dobruja (in understanding of Strashimirov, 1974) strait that occupied the Novo-Bateevo, Tervella, and Silistry areas in the west and extended eastward north of Konstantsa and Chernavody of Romania (Kojumdgieva and Popov, 1981). This strait probably functioned also earlier, during the Sakaraulian time (Popov *et al.*, 1993). The interchange through the Birlad strait (Nosovskii, 1995) that connected the Eastern Paratethys and Alpine–Carpathian basin crossing eastern Romania during the Konkian period (Didkovskii and Nosovskii, 1975; Roshka, 1981; Goncharova and Il'ina, 1997) was less probable during the Tarkhanian, because fauna of the Dniester–Prut interfluve (the zone of possible contact) is impoverished and lacks immigrants from the neighboring (Karpatian) basin.

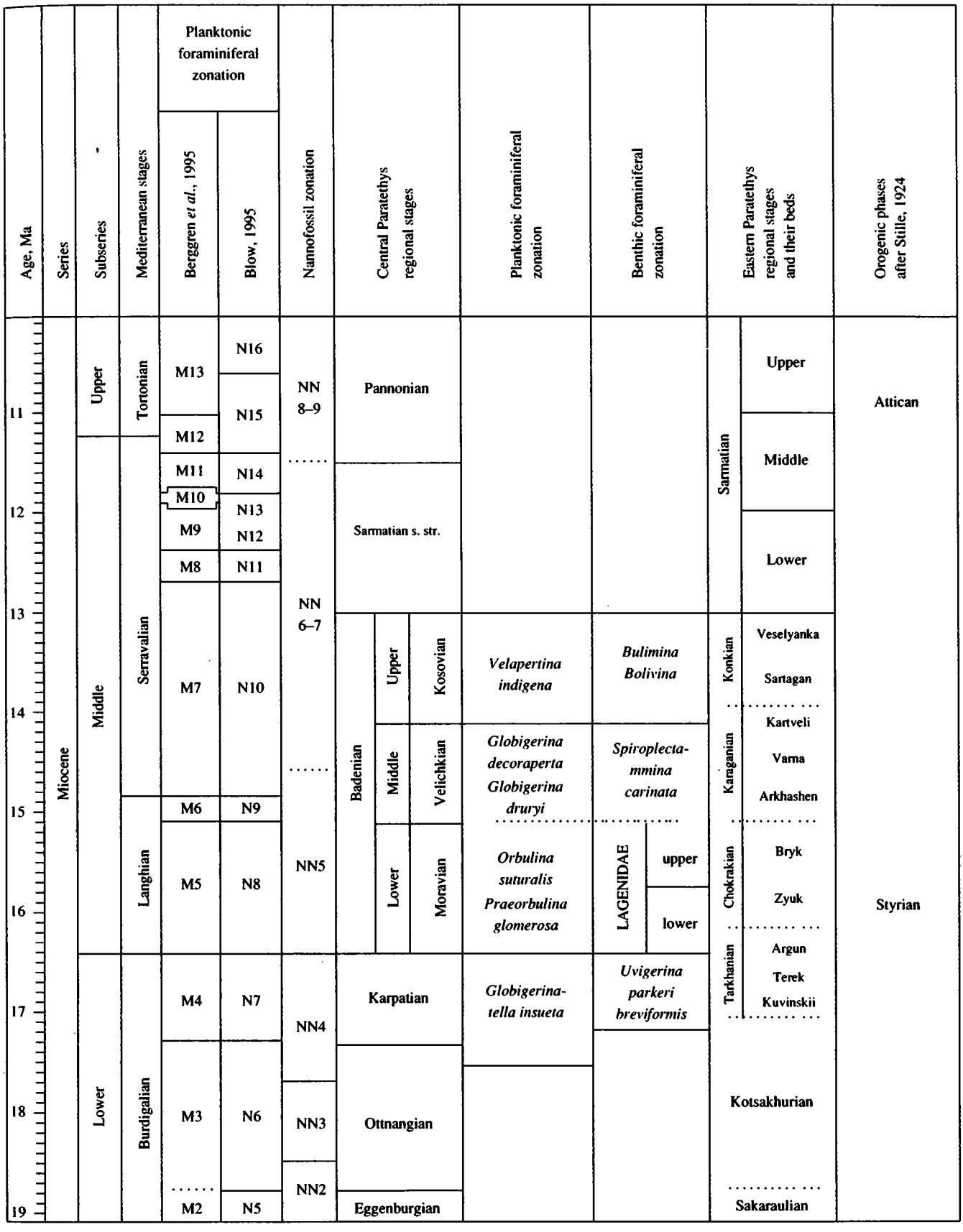
Simultaneously, the Eastern Paratethys acquired links with the Eastern Mediterranean (through the South Van and Aleppo–Urfa straits) and Indo-Pacific realm of the Tethys (via the Central Iranian basin; Goncharova and Shcherba, 1997).[2]

The early Tarkhanian basin widened, as compared with the Kotsakhurian one, in the west and northwest. In addition, the basin became deeper in general and included vast areas of deep shelf, or lower sublittoral and pseudoabyssal zones (depth interval of 150–300 m according to Zhizhchenko, 1940). This resulted in accumulation of calcareous ooze within the entire basin. In near-shore areas (shallow shelf, or upper sublittoral zone up to 50 m), sediments were enriched in terrigenous material varying in size from silt to pebbles. Transgression from the Western Paratethys and Tethys resulted in rapid occupation of shoals by the diverse and abundant benthic fauna of sea urchins, crabs, brachiopods, corals (Kvaliashvili, 1979), benthic foraminifers (Bogdanovich, 1965), ostracods that included, in addition to forms inherited from the Kotsakhurian basin, the polyhaline Mediterranean species *Cytheridea muelleri* (Munst.) (Shneider, 1975), and gastropods (Il'ina, 1993). Abundant bivalves (62 species; Goncharova, 1989) formed coquinas and characteristic oyster banks composed mainly of *Crassostrea gryphoides* and spread over the entire shallow part of the basin. These shell accumulations were characteristic of the South Dobruja trough, northern Black Sea gulf, slopes of the Crimean uplift, the Lechkhumi–Chkumi and Gori–Uplistsikhe areas in western and eastern peripheries of the Dzirul massif, northwestern slopes of the Talysh Mountains up to the Melikkasum Ridge in the east, Krasnovodsk, Fore-Kopetdag, and North Ustyurt gulfs.

The floor of deeper zones of the shelf subsided down to the level of the lower sublittoral zone. These areas included western slopes of the West Kuban' (Bogdanovich, 1965) and Terek–Caspian depressions, the Abkhazia relic of the Tuapse depression in the Transcaucasia region (the Dzhgali area) and, probably, Dzhebraili depression (Alizade *et al.*, 1980, p. 68). The pseudoabyssal zone included the Kerch'–Taman' depression, southern areas of the West Kuban' (Shcherik, 1973) and Terek–Caspian depressions of the Ciscaucasia (*Neogenovaya sistema*, 1986), Iori depression of the Transcaucasia region, and central part of the Fore-Kopetdag depression. Past deep-sea zones of the Euxinian–Caspian basin such as the Kolkhida part of the East Black Sea–Trialeti depression (Bia, Khobi, Patratsukha), Fore-Talysh and Kobystan depressions (central Kobystan, Apsheron Peninsula, and Caspian–Kuba area; Alizade *et al.*, 1980) virtually preserved their

[2] Both straits were previously termed as the Zagros strait (Goncharova and Shcherba, 1997).

Correlation of middle Miocene regional stages of the Eastern Paratethys with regional stages of the Western (Central) Paratethys and Mediterranean stages (Studencka *et al.*, 1998, with modifications and additions)



bathyal–abyssal bathymetric position. Bottom waters in some pseudoabyssal areas were still H_2S-contaminated and their benthic biota was impoverished. Locally (Kerch' Peninsula, southern areas of the West Kuban' and Terek–Caspian depressions, Kobystan), these deep areas were probably free of any life at all. Benthic community of the pseudoabyssal zone was impoverished, represented by euryoxybiontic bivalves *Nucula nucleus, Abra parabilis, Nuculana subfragilis, Corbula gibba, Thyasira flexuosa*, and, probably, by gastropods (nassariids). In the lower sublittoral zone, present were also rare *Lentipecten corneus denudatus, Lunatia helicina*, and *Aporrhais pespelecani*, in addition to molluscan species listed above.

The pelagic zone was occupied by Clupeidae and Gadidae (Sychevskaya in Goncharova, 1989), and near-surface carnivorous fishes of the *Caranx* genus. In opinion of paleoichthyologists, this fauna is close to the Mediterranean one (*Neogenovaya sistema*, 1986b). The pelagic conditions were favorable for development of planktonic foraminifers (*Globorotalia, Globigerinoides, Globigerina, Planorotalia*; Nosovskii *et al.*, 1976) and pteropods (*Spiratella*).

In addition to the newly appeared planktonic, nektonic, and benthic marine species, biota of the Tarkhanian basin retained relics of the brackish-water Kotsakhurian fauna: *Rzehakia dubiosa* (Hoern.), *Saccammina zurumakensis* Bogd., and shallow-water sea urchin *Syngnathus altus* Dan. (Merklin *et al.*, 1964; Bogdanovich, 1965; *Neogenovaya sistema*, 1986b; Goncharova, 1989). *Rzehakia* forms populated shoals (lagoons with congerias and near-shore sea areas) and colonized deep-sea zones of the basin, sometimes as sole representatives of the molluscan fauna (the pseudoabyssal zone of the Fore-Kopetdag depression; Goncharova, 1989).

In the mid-Tarkhanian time, the bottom topography of the basin shelf was again flattened. The lower sublittoral zone became wider owing to shoaling of some pseudoabyssal areas (the Kerch' part of the periclinal depression in the western Caucasus, Fore-Kopetdag and, partly, Terek–Caspian depression, and Iori depression that, as evident from its fauna, could partly correspond to the pseudoabyssal zone) and deepening of upper sublittoral areas, which were preserved only on the summit of the Schatsky swell (the Rioni River middle courses; Bagdasaryan, 1970).[3] The pseudoabyssal zone existed only in southern areas of the West Kuban' and Terek–Caspian deep shelf troughs and in the Kobystan and Fore-Talysh deep-sea depressions. Data on other deep-sea depressions that were well developed in the early Tarkhanian are unknown. The middle Tarkhanian basin had slightly restricted faunal exchange with the World Ocean, as it is evident from increased endemism of bivalve mollusks and from the reduced share of migrants in their assemblage (Goncharova, 1989). Nevertheless, fauna of the Tarkhanian basin was still abundant and diverse. More than a half of 60 molluscan species were represented by polyhaline Mediterranean forms, among which *Nucula nucleus, Lentipecten corneus denudatus, Neopycnodonte navicularis, Lunatia helicina*, and *Aporrhais pespelecani* were most abundant and widespread in the lower sublittoral zone, where they frequently formed coquinas. Coquinas and oyster bank composed of *Neopycnodonte navicularis* were populated by Polychaeta genera *Serpula* and *Spirorbis*, by bryozoans of the Cyclostomida (genus *Crisia*) and Cheilostomida (genera *Scrupocellaria* and *Puellina*) orders (Veis, 1988), and by barnacles (genus *Balanus*). Muddy and sandy–muddy substrates of the lower sublittoral zone near the Dzirul massif (Gorisa and Khorshi areas; Bagdasaryan, 1965) and in areas of the western (Goncharova, 1989) and eastern Ciscaucasia (Merklin, 1948), Krasnovodsk plateau and Fore-Kopetdag depression hosted sea urchins of the *Schizaster* genus. Rare free-living lunulitiform bryozoans (genera *Lunulites, Cupulardia, Discoporella, Lunularia*; L.A. Viskova, personal communication) populated soft substrates.

In shoals (the upper sublittoral zone) covered by oyster coquinas (less common as compared with the early Tarkhanian), most abundant were venerids (*Pelecyora islandicoides*), pectinids (*Lentipecten nucleus denudatus*), cardiids (*Acantocardia centumpania*), corbulids, *Ervilia* forms, and gastropods *Calyptraea chinensis* (L.). Areas with coquinas and harder substrates were also populated by Polychaeta species, bryozoans, and barnacles. Crabs were common. *Rzehakia* forms occurring only in some areas of Georgia almost completely disappeared from the sublittoral zone. Benthic foraminiferal community included, along with euryhaline families, abundant nodosariids and textulariids (Bogdanovich, 1947, 1965; Krasheninnikov, 1959; Bogdanovich and Goncharova, 1976). Ostracods were dominated by polyhaline Mediterranean genera *Xestoleberis, Cytheretta, Aurilia, Aglajocypris, Bathocythere*, and *Eucythere* (Shneider, 1975; *Neogenovaya sistema*, 1986b).

The pseudoabyssal benthic community changed less than others. Detritivorous bivalves *Abra, Nuculana, Thyasira*, and *Nucula* completely replaced its *Rzehakia* forms.

The noticeable share of the planktonic community was represented by pteropods (*Spiratella*) and foraminiferal genera *Globigerina* (in particular *G. tarchanensis*), *Globorotalia*, and *Planorotalia* (Nosovskii *et al.*, 1976; *Neogenovaya sistema*, 1986b). Associated

[3] An assumption that the Gori (Ananiashvili, 1985) and Tomakovka (Nosovskii, 1998) beds represent the middle Tarkhanian shallow-water facies needs in additional substantiation. For instance, the early Tarkhanian age of the Gori foraminiferal assemblage (Dzhanelidze, 1970) as well as paleomagnetic data (Trubikhin, personal communication) indicating the reversed polarity of the Gori Beds of Georgia and normal polarity of the "Tarkhanian Marl" (middle Tarkhanian) in the Tarkhanian hypostratotype (Malyi Kamyshlak Ravine) contradict this assumption.

pseudoplanktonic forms were goose barnacle *Lepas miocenica* (Reuss) (determination by A.S. Alekseev). Marine fishes became more diverse (Bannikov and Parin, 1997), but their assemblage was still close to that of the early Tarkhanian time. Most abundant among fishes were representatives of Clupeidae (*Neogenovaya sistema*, 1986b).

In the late Tarkhanian, the basin deepened further, especially in the outer part of the Eurasian shelf. In the western Transcaucasia, there were, like in the mid-Tarkhanian time, shoals with coquina substrates, but *Crassostrea gryphoides* played a subordinate role and *Neopycnodonte navicularis* virtually disappeared from shell accumulations. The Tarkhanian oyster coquinas composed of highly variable species *Crassostrea gryphoides* and *Ostrea lamellosa* first appeared in deeper Dzhebraili and Fore-Talysh troughs (in the northeastern slope of Talysh; Alizade *et al.*, 1980). There is also evidence (Zhizhchenko, 1940) indicating that oyster banks were also present in the northeastern areas of the Terek–Caspian depressions (the Yaryk-su River between the Terek and Sulak rivers), and this suggests continuation of shoaling in this part of the basin. Remains of shallow-water fishes *Mioblennius fraudulentus* of the Blennidae family (Bannikov, 1996) occurring in the pseudoabyssal facies of the Apsheron Peninsula (Sumgait River, Azerbaijan) were probably transported from shoals located in the northwest. In the initial late Tarkhanian, the lower sublittoral zone of the Kartli and Rioni subsided areas of the Dzirul massif hosted abundant sea urchins (Bagdasaryan, 1965). During the late Tarkhanian, bottom waters in the deepest part of the basin were intermittently oxygen-deficient (Merklin, 1950; Bagdasaryan, 1965). Links of the Tarkhanian basin with the World Ocean were further reduced. The growing isolation was accompanied by the increased influx of terrigenous material into the basin (Zhizhchenko, 1940; Bagdasaryan, 1965) that influenced development of the late Tarkhanian fauna. During the Argunian time, some groups of marine organisms became impoverished, but pteropod mollusks *Spiratella* were abundant (Bogdanovich and Goncharova, 1976). Among bivalves, the number of immigrants decreased, but their endemism increased, although the total diversity remained virtually the same (59 species). Some polyhaline Mediterranean molluscan species disappeared together with their characteristic Tarkhanian forms and benthic foraminifers of the Nodosariida and Textulariida orders (Bogdanovich and Goncharova, 1976; Bogdanovich in Goncharova, 1989). By contrast, ostracods became more diverse at the generic and species levels, mainly owing to increased abundance of euryhaline forms (Shneider, 1975; *Neogenovaya sistema*, 1986b). Polychaeta were represented by species of the genus *Pectinariopsis* whose tubes were composed of *Spiratella* shells. Polyhaline *Lepas miocenica* (Reuss), which were found in the pseudoabyssal facies of the Crimea attached to different floating pieces, e.g., to wood fragments and sargasso algae (*Sargassum, Cystosera*; determination by M.A. Akhmet'ev), continued to exist until the end of the Argunian time. Planktonic foraminifers represented, like in the middle Tarkhanian, by *Globorotalia, Planorotalia*, and *Globigerina* (with most abundant *G. tarchanensis*; Bogdanovich, 1965) species became scarce by the end of the Argunian time and soon disappeared completely (Pishvanova in Goncharova, 1989). Nannoplankton was highly impoverished and rare at that time (Andreeva-Grigorovich and Savitskaya, 2000).

Nevertheless, the basin preserved marine environments. Periods of mass mortality in the pseudoabyssal zone, when the benthic life became scarce or disappeared because of bottom water contamination with H_2S, alternated with periods of sufficient water aeration (Merklin, 1950), when the basin was colonized again by benthic organisms. During such periods, benthic community included brittle stars and sea urchins, whereas the nektonic assemblage was represented, in addition to Clupeidae, Gadidae, and *Caranx* fishes inherited from the middle Tarkhanian, also by mesopelagic *Lotella andrussovi* (Bogatchev) (*Iskopaemye kostistye...*, 1980) and deep-water forms, such as phosphorescent anchovy *Vinciqueria merklini* Dan (*Neogenovaya sistema*, 1986b; Sychevskaya in Goncharova, 1989; Bannikov and Parin, 1997). The Eastern Paratethys was again invaded by *Bregmaceros filamentosus* (Priem) of the Bregmacerotidae family (*Neogenovaya sistema*, 1986b). This bathypelagic species of open seas is recorded in the Eocene–lower Oligocene sediments of the Caucasus and Oligocene sequences of southern Iran (*Iskopaemye kostistye...*, 1980).[4] The nannoplankton (Muzylev and Golovina, 1987) and fish (Bannikov, 1984) assemblages include also the Indo-Pacific immigrants. The Tarkhanian dinocyst assemblages contain, similarly to their Chokrakian and, to a lesser extent, Karaganian counterparts, many taxons in common with the coeval Mediterranean assemblages (M.A. Akhmet'ev, personal communication). By the end of the late Tarkhanian, the pseudoabyssal fauna that existed in deep areas of the eastern Crimea (Merklin, 1950), Taman', and Ciscaucasia (Zhizhchenko, 1940) was replaced by the community characteristic of the lower sublittoral zone, which indicate the general basin shoaling.

Thus, based on the fauna characteristics, we can assume that marine environments (30–32‰) in the basin retained during the entire Tarkhanian period, though its salinity was probably slightly lower in the middle and late Tarkhanian (Goncharova, 1989). The paleobathymetric zoning of the Tarkhanian basin preserved some features that were characteristic of its ear-

[4] All listed fish species originate from *Spirialis* Clays (Argun Beds), the age of which is interpreted differently. For instance, authors of the book *Iskopamye kostistye ryby SSSR* suggest the Tarkhanian and Chokrakian ages for the lower and upper parts of this unit, respectively.

lier Paleogene stage of evolution, but were significantly transformed in the subsequent Chokrakian time.

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REFERENCES

Adams, C.G., Gentry, A.W., and Whybrow, P.J., Dating the Terminal Tethyan Event, *Utrecht Micropal. Bull.*, 1983, no. 30, pp. 273–298.

Akhmet'ev, M.A., *Fitostratigrafiya kontinental'nykh otlozhenii paleogena i miotsena Vnetropicheskoi Azii* (Phytostratigraphy of Paleocene and Miocene Continental Sediments in Extratropical Asia), Moscow: Nauka, 1993.

Akhmetiev, M.A., Paleobotanical Data on the Geological Age in the Greater Caucasus Land, *Palaeobotanical J.*, 1995, vol. 29, no. 1a, pp. 172–181.

Alizade, K.A., Azizbekova, A.A., and Ataeva, E.Z., *Oligotsen-miotsenovye otlozheniya Talysha, yugo-vostochnogo okonchaniya Malogo Kavkaza (Dzhebrail'skii raion) i Nakhichevanskogo progiba (Stratigrafiya i fauna)* (Oligocene–Miocene Sediments of the Talysh, Southeastern Terminus of the Lesser Caucasus, Dzhebrail District, and Nakhichevan Trough: Stratigraphy and Fauna), Baku: Inst. Geol. Akad. Nauk AzSSR, 1980.

Ananiashvili, G.D., *Territoriya Gruzii i smezhnye s nei regiony v tarkhanskoe vremya* (Territory of Georgia and Adjacent Regions in the Tarkhanian Time), Tbilisi: Metsniereba, 1985.

Ananianashvili, G., On Biostratigraphy of Middle Miocene Sediments of Eastern Paratethys, *Bull. Georgian Acad. Sci.*, 1999, vol. 160, no. 3, pp. 495-497.

Andreyeva-Grigorovich, A.S., Savytskaya, N.A., Nannoplankton of the Tarkhanian Deposits of the Kerch Peninsula (Crimea), *Geol. Carpathica*, 2000, vol. 51, no. 6, pp. 399–406.

Andrusov, N.I., *Izbrannye trudy* (Selected Works), Moscow: Nauka, 1961, vol. 1, 1963, vol. 2, 1964, vol. 3.

Atlas litologo-paleogeograficheskikh kart Russkoi platformy i ee geosinklinal'nogo obramleniya (Atlas of Lithological-Paleogeographic Maps of the Russian Platform and Its Geosynclinal Framing), Moscow: Vses. Aerogeol. Trest, 1962, sheet 77.

Atlas litologo-paleogeograficheskikh kart SSSR (Atlas of Lithological–Paleogeographic Maps of the Russian Platform), Moscow: Vses. Aerogeol. Trest, 1967, vol. 4, sheet 45.

Bagdasaryan, K.G., *Razvitie mollyuskovoi fauny chokraka Gruzii* (Evolution of the Chokrakian Molluscan Fauna in Georgia), Tbilisi: Metsniereba, 1965.

Bagdasaryan, K.G., *Fauna mollyuskov tarkhanskogo gorizonta i usloviya ee sushchestvovaniya* (Fauna of Mollusks from Tarkhanian Horizon and Its Habitat Environments), Tbilisi: Metsniereba, 1970.

Baldi, T., The Early History of the Paratethys, *Foldt. Kozlony*, 1980, vol. 110, no. 3/4, pp. 456–471.

Bannikov, A.F., Genus *Scomberoides* (Teleostei) in Miocene Deposits of the Caucasus, *Paleontol. Zh.*, 1984, no. 1, pp. 108–110.

Bannikov, A.F., New Dogwise Fishes of Families Blennidae and Clinidae (*Perciformes*) from the Miocene of Paratethys, *Paleontol. Zh.*, 1998, no. 4, pp. 63–67.

Bannikov, A.F. and Parin, N.N., The List of Marine Fishes from Cenozoic (Upper Paleocene–Middle Miocene) Localities of Southwestern Russia and Adjacent Countries, *Vopr. Ikhtiol.*, 1997, no. 2, pp. 149–161.

Barg, I.M., *Biostratigrafiya verkhnego kainozoya Yuzhnoi Ukrainy* (The Upper Cenozoic Biostratigraphy of the Southern Ukraine), Dnepropetrovsk: Dnepropetrovsk. Gos. Univ., 1993.

Bekker-Migdisova, E.E., *Tretichnye ravnokrylye Stavropol'ya* (Tertiary Homoptera of Stavropol' Region), Moscow: Nauka, 1964.

Belokrys, L.S., Spirorbis of the Black Sea Region Miocene, *Paleontol. Zh.*, 1984, no. 2, pp. 24–39.

Berggren, W.A., Kent, D.A., Swisher, C.C., and Aubry, M.P., A Revised Cenozoic Geochronology and Chronostratigraphy. Geochronology Timescales and Global Stratigraphic Correlation, *SEPM Special Publication*, Tulsa, Oklahoma: 1995, no. 54, pp. 129–212.

Blow, W.H., Late Middle Eocene to Recent Planktonic Foraminiferal Biostratigraphy, Bronniman, P. and Renz, H.H., Eds., *Proc. First Intern. Conf. on Planktonic Microfossils (Geneva, 1967)*, Leiden, E J Brill, 1969, vol. 1, pp. 199–421.

Bogdanovich, A.K. and Goncharova, I.A., The Life Conditions and the Change in Composition of Late Tarkhanian Foraminifera and Bivalves in the Kerch Peninsula, *Byull. Mosk. O–va Ispyt. Prir., Otd. Geol.*, 1976, vol. 51, no. 2, pp. 155–156.

Bogdanovich, A.K., Results of Study on Foraminifera from the Miocene of the Caucasus–Crimea Region, *Mikrofauna neftyanykh mestorozhdenii Kavkaza, Emby i Srednei Azii* (Microfauna from Oil Fields of the Caucasus, Emba, and Central Asia), Leningrad: Gostoptekhizdat, 1947.

Bogdanovich, A.K., Stratigraphic and Facies Distribution of Miocene Foraminifera in the Western Ciscaucasia and Problems of Their Genesis, *Tr. Krasnodar. Filiala VNIPI Neft'*, 1965, no. 16, pp. 300–351.

Bogdanovich, A.K., Evolution Stages of Foraminifera Fauna of the Miocene in the Northern Caucasus and Problems of Genesis, *Mem. Bur. rech. geol. et minieres*, 1974, vol. 2, no. 78, pp. 739–744.

Burova, Zh.V. and Panova, L.A., Specific Features of Miocene Palynoflora in the Southern Part of West European Platform, *Opornye razrezy neogena Vostochnogo Paratetisa (Tamanskii poluostrov)* (Reference Sections of the Neogene in the Eastern Paratethys, Taman' Peninsula), Volgograd-Taman': Volgograd. Geol.-Razved. Eksp. Min. Prir. Resursov RF, 1998, pp. 45–46.

Chel'tsov, Yu.G., Kleiner, Yu.M., and Sholokhov, V.V., The Neogene of Northern and Eastern Kara-Bogaz Regions *Izv. Vyssh. Uchebn. Zaved., Geol. Razved.*, 1967, no. 3, pp. 26–35.

Cicha, I., Papp, A., Seneš, J., and Steininger, F. F., Badenian, *Proc. VIth R.C.M.N.S. Congress*, Bratislava:Veda, 1975, no. 1, pp. 43–49.

Cicha, I., Seneš, J., Steininger, F. F., Karpatian, *Proc. VIth R.C.M.N.S. Congress Bratislava 1975. Bratislava*, Veda, 1975, no. 1, pp. 93–100.

Deryugin, K.M., Fauna of the Kola Gulf and Its Habitat Environments, *Zap. Imperator. Akad. Nauk. Fiz. Mat. Otd.*, 1915, vol. 8, no. 1.

Didkovs'kii, V.Ya. and Nosovs'kii, M.F., The Black Sea Depression: Miocene, *Stratigrafiya URSR* (Stratigraphy of URSR, vol. 10: Neogene), Kiev: Naukova Dumka, 1975, pp. 32–70.

Dlusskii, G.M., *Murav'i pustyn'* (Desert Ants), Moscow: Nauka, 1981, pp. 64–82.

Dzhanelidze, O.I., *Foraminifery nizhnego i srednego miotsena Gruzii* (Foraminifera of the Lower and Middle Eocene in Georgia), Tbilisi: Metsniereba, 1970.

Gabuniya, L.K. and Bendukidze, O.G., Small Mammalia of Belomechetskaya Site (Northern Caucasus, Chokrakian) and Their Biostratigraphic Significance, *Soobshch. Akad. Nauk Gruz. SSR*, 1984, vol. 113, no. 1, pp. 93–95.

Goncharova, I.A., *Dvustvorchatye mollyuski tarkhanskogo i chokrakskogo basseinov* (Bivalves of the Tarkhanian and Chokrakian Basins), Moscow: Nauka, 1989.

Goncharova, I.A., Tarkhanian–Karaganian Cycle (Miocene) in Development of the Eastern Paratethys: Correlation, Hydrology and Paleobiogeography, *Byul. Mosk. Obshch. Ispyt. Prir., Otd. Geol.*, 1991, vol. 66, issue 4, pp. 81–84.

Goncharova, I.A. and Il'ina, L.B., Relations between the Middle Miocene Basins of the Western and Eastern Paratethys, *Stratigr. Geol. Korrelyatsiya*, 1997, vol. 5, no. 6, pp. 74–82.

Goncharova, I.A. and Shcherba, I.G., Paratethys at End of the Early–Middle Miocene and Its Relation with Surrounding Basins, *Stratigr. Geol. Korrelyatsiya*, 1997, vol. 5, no. 3, pp. 102–107.

Grossgeim, V.A. and Gladkova, A.N., New Data on the Structure of the Karaganian Land in the Eastern Caucasus, *Dokl. Akad. Nauk SSSR, Novaya Ser.*, 1950, vol. 73, no. 1, pp. 157–159.

Hámor, G., *Neogene Palaeogeographic Atlas of Central and Eastern Europe*, Budapest: Hungar. Geol. Inst., 1988, Map 4.

Il'ina, L.B., *Opredelitel' morskikh srednemiotsenovykh gastropod Yugo-Zapadnoi Evrazii* (Guide Book on Mediterranean Gastropoda of Southwestern Evrasia), Moscow: Nauka, 1993.

Iskopaemye kostistye ryby SSSR (Fossil Osseous Fishes of the Soviet Union), Moscow: Nauka, 1980.

Ivanova, T.A., Foraminifera-Based Biostratigraphy of Miocene Sediments in the Crimean Plain, *Cand. Sci. (Geol.–Miner.) Dissertation*, Kiev, 1999.

Ivanova, T.A., Barg, I.M., and Bogdanovich, E.M., Tarkhanian Regional Stage of the Crimean Plain, *Izv. Vyssh. Ucheb. Zaved. Geol. Razved.*, 1998, no. 2, pp. 44–50.

Ivanova, T.A., Sibiryakova, O.P., and Bogdanovich, E.M., To the Problem of the Spirialis Clay Age in the Crimea, *Tr. Mezhdunar. konf. "Problemy geologii i osvoeniya nedr."* (Proc. Int. Conf. on the Problem of Geology and Development of the Earth's Interiors), Tomsk: Tomsk. Politekhn. Inst., 1998, vol. 1, pp. 30–31.

Kojumdgieva, E.I. and Popov, N.G., Regions strukturo-paleogeographiques en Bulgarie du Nord-Est pendant le Neogene, *Compt Rendus. L'Academie Bulgarie du Nord-Est Pendant Le Neogene*, 1981, vol. 34, no. 9, pp. 1273–1275.

Konenkova, I.D. and Bogdanovich, E.M., Distribution of Foraminifera and Nannoplankton in the Tarkhanian–Chokrakian Sediments of the Malyi Kamyshlak Area (Kerch Peninsula), *Biosferi geologichnogo minulogo Ukraini*, Kiev: I GN NAN Ukr, 1994, pp. 95–96.

Kopp, M.L. and Shcherba, I.G., The Caucasian Basin in the Paleogene, *Geotektonika*, 1998, no. 2, pp. 29–59.

Krasheninnikov, V.A., Foraminifera, *Atlas srednemiotsenovoi fauny Severnogo Kavkaza i Kryma* (Atlas of the Middle Miocene Fauna from Northern Caucasus and Crimea), Moscow: Gostoptekhizdat, 1959, pp. 15–103.

Krasheninnikov, V.A., Basov, I.A., Golovina, L.A., *et al.*, *The Miocene of Northeastern Atlantic and Eastern Mediterranean* (Biostratigraphy, Paleoecology, and Paleogeography), Moscow: Nauchnyi Mir, 1999.

Kravchuk, V.N. and Volchegurskii, L.F., New Findings of the Middle and Upper Miocene Sediments in the Eastern Caspian Sea Region, *Byull. Mosk. O–va Ispyt. Prir., Otd. Geol.*, 1975, vol. 50, no. 1, pp. 40–44.

Kulichenko, V.G. and Popov, N.G., *Korrelyatsiya neogenovykh otlozhenii chernomorskikh poberezhii i shel'fa Bolgarii i Ukrainy* (Correlation of the Neogene Sediments in the Black Sea Coasts and Shelf of Bulgaria and Ukraine), Kiev: Inst. Geol. Nauk Akad. Nauk Ukr. SSR, 1987.

Kunitskaya, T.N., Pozharskaya, T.F., Solov'eva, N.S., *et al.*, Facies and Paleogeographic Environment of Accumulation of the Mesozoic and Cenozoic Sediments in Central Asia and Southern Regions of Kazakhstan, *Geologiya neftegazonosnykh oblastei Srednei Azii i Yuzhnogo Kazakhstana* (Geology of Oil and Gas Fields in Central Asia and Kazakhstan), Moscow: Nedra, 1969, pp. 58–102.

Kvaliashvili, G.A., *Osnovnye etapy razvitiya morskikh mollyuskov srednego miotsena Chernomorskoi oblasti* (Main Stages in the Middle Miocene Evolution of Marine Mollusks in the Black Sea Region), Tbilisi: Metsniereba, 1979.

Laskarev, V., Sur les equivalents du sarmatien superier en Serbie, *Rec. Travaus Offert a M. Jovan Cvijic par ses amis et collaborateurs a l'ocassion de ses trente-cinq ans de travail scientifique*, Beograd, 1924, pp. 1–13.

Mchedlishvili, P.A., To the Paleogeography of the Caucasus in the Karaganian Age in Connection with Paleobotanical Data, *Dokl. Akad. Nauk SSSR*, 1951, vol. 81, no. 5, pp. 921–923.

Merklin, R.L., On Variability of *Leda subfragilis* R. Hoern. Group in the Tarkhanian Basin, *Izv. Akad. Nauk SSSR, Ser. Biol.*, 1948, no. 2, pp. 225–234.

Merklin, R.L., *Plastinchatozhabernye spirialisovykh glin, ikh sreda i zhizn'* (Elasmobranchii of *Spirialis* Clays), Moscow: Akad. Nauk SSSR, 1950.

Merklin, R.L., Bogdanovich, A.K., and Buryak, V.N., On Fauna from the Upper Part of Ritsian Sediments of the Kuban' and Bol'shoi Zelenchuk Rivers, *Byull. Mosk. O–va Ispyt. Prir., Otd. Geol.*, 1964, vol. 39, no. 4, pp. 52–56.

Milanovskii, E.K. and Khain, V.E., *Geologicheskoe stroenie Kavkaza* (Ceological Structure of the Caucasus), Moscow: Mosk. Gos. Univ., 1963.

Molostovskii, E.A. and Khramov, A.N., *Magnitostratigrafiya i ee znachenie v geologii* (Magnetostratigraphy and Its Significance in Geology), Saratov: Saratov. Univ., 1997.

Muzylev, N.G. and Golovina, L.A., Relation between the Eastern Paratethys and World Ocean in the Early–Middle Miocene, *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1987, no. 12, pp. 62–72.

Neogenovaya sistema. Polutom 1. Stratigrafiya SSSR (The Neogene System. Semivolume 1. Stratigraphy of the Soviet Union), Muratov, M.V. and Nevesskaya, L.A., Eds., Moscow: Nedra, 1986.

Neogenovaya sistema. Polutom 2. Stratigrafiya SSSR (The Neogene System. Semitom 2. Stratigraphy of the Soviet Union), Muratov, M.V. and Nevesskaya, L.A., Eds., Moscow: Nedra, 1986.

Nicolov, P.I., New Elements of the Molluscs Fauna from the Karapelit Formation, NE Bulgaria, *Materials of Symposium Neogene Stratigraphy and Palaeontology of Kerch and Taman Peninsulas. 4-12 th June 1996. Moscow-Krasnodar-Anapa*, Russian Commitee for IGCP, 1996, pp. 27, 28.

Nosovsky, M.F., Paleogeographic Links between Mocene Sea Basins of South Ukraine and the Mediterranean Region. Abstracts, of the Xth R.C.M.N.S Congress. Bucharest, September, 1995, *Romanian J. Stratigraphy*, 1995, vol. 76 (suppl. 7, 1), pp. 175–176.

Nosovskii, M.F., Geological and Biotic Events of the Oligocene, Early and Middle Miocene in the Northern Black Sea Region, *Byull. Mosk. O–va Ispyt. Prir., Otd. Geol.*, 1998, vol. 73, no. 3, pp. 44–50.

Nosovskii, M.F., Barg, I.M., Pishvanova, L.S., and Andreeva-Grigorovich, A.I., On the Tarkhanian Stage Range in the Southern Soviet Union, *Stratigrafiya kainozoya Severnogo Prichernomor'ya i Kryma* (The Cenozoic Stratigraphy of the Black Sea Region), Dnepropetrovsk: Dnepropetrovsk. Gos. Univ., 1976, pp. 22–31.

Pol'ster, L.A. and Kravchenko, M.F., The Miocene Evolutionary Stage, *Geologiya i neftegazonosnost' Yuga SSSR. Prikarabogaz'e* (Geology and Oil and Gas Resources of the Southern Soviet Union: Kara Bogaz Region), Leningrad: Nedra, 1964, pp. 204–219.

Popov, S.V., Akhmet'ev, M.A., Zaporozhets, N.I., *et al.*, Evolution of the Eastern Paratethys in the Late Eocene–Early Miocene, *Stratigr. Geol. Korrelyatsiya*, 1993, vol. 1, no. 6, pp. 10–39.

Prisyazhnyuk, V.A., Lyul'eva, S.A., Syabryai, S.V., *et al.*, New Data on Paleontology and Stratigraphy of the Miocene Sediments in Ustechkivskii Graben of Volhynia-Podolia Region, *Geol. Zh.*, 1997, nos. 1, 2, pp. 57–64.

Purtseladze, Kh.N., Palynological Assemblage of the Tarkhanian Regional Stage in Western Georgiay, *Tr. Zap. Sib. Nauchno-Issled. Geol.-Razved. Neft. Inst.*, 1983, no. 179, pp. 46–48.

Radionova, E.P., *Stratigrafiya neogena tropicheskoi oblasti Tikhogo okeana po diatomeyam* (The Diatom-Based Neogene Stratigraphy of Tropical Region in the Pacific Ocean), Moscow: Nauka, 1991.

Ramishvili, I.Sh., Application of Palynological Data For Correlation of Neogene Sediments in Several Regions of the Paratethys, *Tr. Zap.-Sib. Nauchno-Issled. Geol. Razved. Neft. Inst.*, 1983, no. 179, pp. 56–61.

Rögl, F., Paleogeographic Considerations for Mediterranean and Paratethys Seaways (Oligocene to Miocene), *Ann. Naturhist. Mus. Wien*, 1998, 99A, pp. 279–310.

Roshka, V.Kh. and Khubka, A.N., Outline of the Neogene Stratigraphy in the Dniester-Prut Interfluve, *Biostratigrafiya antropogena i neogena Yugo-Zapada SSSR* (Biostratigraphy of the Anthropogene and Neogene in the Southwestern Soviet Union), Chisinau: Shtiintsa, 1981, pp. 78–107.

Shcherba, I.G., *Etapy i fazy kainozoiskogo razvitiya Al'piiskoi oblasti* (Stages and Phases in Cenozoic Evolution of the Alpine region), Moscow: Nauka, 1993.

Shneider, G.F., Ostracoda from the Neogene Sediments in Southern Russia, *Tr. YI Kongressa RKSMN* (Proc. VI Congr. RCMNS), Bratislava, 1975, vol. 1, pp. 163–171.

Sholokhov, V.V., History of Most Recent Geological Evolution and Results of the Structural-Geomorphological Study in the Southern Ustyurt, *Cand. Sci. (Geol.–Miner.) Dissertation*, Moscow: Moscow State University, 1969.

Sorochan, O.A., *Stratigrafiya srednemiotsenovykh vidkladiv Volino-Podil'skoi skhilu Ukrains'kogo kristalichnogo shchita za faunoyu peletsipod* (Stratigraphy of the Middle Miocene Sediments on Volhynia-Podolia Slope of the Ukrainian Shield, Implication of Pelecypod Fauna), Kiev: Vid. Akad. Nauk USSR, 1958.

Steininger, F.F., Rögl, F., and Dermitzakis, M., Report on the Round Table Discussion: "Mediterranean and Paratethys Corelations", *Proc. VIII R.C.M.N.S. Congress, 1987*, Budapest: Ann. Inst. Geol. Publ. Hungarici. 70, 1987, pp. 397–421.

Stille, H., *Grundfragen der vergleichenden Tektonik*, Berlin: Borhtraegen, 1924.

Strashimirov, B., Nalichie na tarkhanski sedimenti v Severoiztochna B"lgariya, *God. Vissh. Min. Geol. Inst.*, 1974, vol. 18, Sv. 2, pp. 21–286.

Studencka, B., Gontsharova, I.A., and Popov, S.V., The Bivalve Faunas as a Basis for Reconstruction of the Middle Miocene History of the Paratethys, *Acta Geol. Polonica*, 1998, vol. 48, no. 3, pp. 285–342.

Syabryai, S.V. and Teslenko, Yu.V., Paleobotanical Studies of Salt-Bearing Sediments of Transcarpathian Region (Ukraine), *Aktual. problemy palinologii na rubezhe tret'ego tysyacheletiya* (Actual Problems of Palynology on the Boundary of the Third Millenium), Moscow: Inst. Geol. Razrabot. Gorn. Iskop., 1999, pp. 289–290.

Temnikova-Topaleva, D.N. and Kozyrenko, T.F., On Diatom Algae from the Chokrakian Sediments of the Western Part of the Eastern Paratethys (Northeastern Bulgaria), *Botan. Zh.*, 1982, vol. 67, pp. 643–647.

Trubikhin, V.M., Paleomagnetic Scale and Stratigraphy of the Neogene–Quaternary Sediments in the Paratethys, *Opornye razrezy neogena Vostochnogo Paratetisa (Tamanskii poluostrov). Tez. dokl.* (Reference Sections of the Neogene in the Eastern Paratethys, Taman' Peninsula. Abstracts of Papers), Volgograd-Taman: Volgograd. Geol.-Razved. Eksp. Min. Prir. Res. RF, 1998, pp. 13–21.

Veis, O.B., *Miotsenovye mshanki Severnogo Kavkaza i Kryma* (Miocene Bryozoa of the Northern Caucasus and Crimea), Moscow: Nauka, 1988.

Zaporozhets, N.I., Palynostratigraphy and Dinocyst Zonation of the Middle Eocene–Lower Miocene Deposits at the Belaya River (Northern Caucasus), *Stratigr. Geol. Korrelyatsiya*, 1999, vol. 7, no. 2, pp. 61–78.

Zhizhchenko, B.P., Lower and Middle Miocene, *Stratigrafiya SSSR* (Stratigraphy of the Soviet Union, vol. 12: Neogene), Moscow: Akad. Nauk SSSR, 1940, pp. 11–227.

Zhizhchenko, B.P., *Atlas srednemiotsenovoi fauny Severnogo Kavkaza i Kryma* (Atlas of Mediterranean Fauna from the Northern Caucasus and Crimea), Moscow: Gosnauchtekhizdat, 1959.

Stratigraphy and Geological Correlation, Vol. 9, No. 5, 2001, pp. 523–526. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 9, No. 5, 2001, pp. 109–112.
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Stratigraphy at the Last International Geological Congress of the XX Century (Rio de Janeiro, Brazil)

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The 31st Session of the International Geological Congress (IGC) was held in Rio de Janeiro (Brazil), August 6–17, 2000. Sessions of the congress have been held since 1878, when the International Union of Geological Sciences (IUGS) was formed. The union activity involves now scientists representing more than 110 countries and 35 social organizations. Like the Olympic Games, the IGC sessions take place every four years and are attended by thousands of geoscientists who thus have a possibility to discuss geological problems, to take part in geological excursions, and to dip into the culture of the host country. In Russia, the IGC sessions were held in 1897, 1937, and 1984.

The IGC sessions are usually organized to review the scientific progress achieved by geologists in different countries, to discuss new ideas, and to outline a strategy for future work. It is significant that they promote an intense exchange of geological information. Each IGC session is an important event for geology outlining development of geological disciplines, stratigraphy included.

The Brazilian Congress was attended by geologists from 90 countries. Statistics for the last five sessions is shown in the following table.

IGC Session	Year	Country, city	Number of countries represented	Number of participants
27	1984	USSR, Moscow	107	5239
28	1989	USA, Washington	104	5786
29	1992	Japan, Kyoto	93	4186
30	1996	China, Beijing	116	6147
31	2000	Brazil, Rio de Janeiro	90	4108
32	2004	Italy, Florence		

At the congress in Brazil, there were 324 and 320 participants from the USA and Russia, respectively.

This session was the last one in the XX century and in some way summarized the advances in geology of the passing century. In the opinion of R. Brett (President of the IUGS during last period) and other scientists, the most significant achievements in geology are as follows: establishment of the plate-tectonics "theory;" new data on evolution of the Solar System; understanding of the Earth structure and complicated interaction of its shells; development of new methods of mineral prospecting (water, oil, gas, and other resources); and a deeper insight into origin and evolution of life. Problems of ecology, which are currently of principal importance, supplement the listed ones.

Some words should be said about the organization of the Brazilian congress. The Organizing Committee was headed by Prof. U. Cordani. Several tens of symposia were set up. Both oral and poster forms of presentation were used. Compact disks of the abstracts received (more than 7000 abstracts, 2% of which belongs to Russia geologists) were distributed. There was an exhibition of geological production (maps, atlases, books, and so on) from different countries. Some geological excursions were organized.

STRATIGRAPHY

This line of geology has received much attention. Important issues discussed at the session were (a) the new version of the International Stratigraphic Chart, (b) the abridged version of the International Stratigraphy Guide (Code), and (c) different aspects of stratigraphic practice. Among the latter, there were considered the combined employing of different (including new) methods of stratigraphic classification and nomenclature (for individual system and series), paleogeographic reconstructions, and others. These problems were discussed at special symposia on Stratigraphy, Paleontology and Historical Geology, Marine Geology, Geological Mapping, and others, and at several meetings of

subcommissions of the International Commission on Stratigraphy (ICS).

NEW VERSION OF INTERNATIONAL STRATIGRAPHIC CHART (ISC)

The ICS acquired its present structure in the 1970s under guidance of V.V. Menner. It consists of 18 subcommissions and committees, which supervise activity on various ISC systems, stratigraphic classification, geochronology, etc., and include 400 voting members and nearly 2000 experts from 109 countries.

The ICS was set up as back as 1878, at the 1st session of the IGC. at the 2nd IGC in 1881, it recommended the first hierarchy scheme of stratigraphic categories, that was authorized at the 8th ISC session in 1990. A slightly modified ISC, where stages and zones were regarded as regional units, was in common use for many decades. An important result of the ICS post-war activity is elaboration of the International Stratigraphic Guide in 1976 (see below). In 1980–1990s, the ISC had to be somewhat revised, because significant materials on biozonation, magnetic and isotopic records became available. For this reason, all subcommissions of the ICS concentrated their efforts on substantiation of stages and their boundaries. New variants of the ISC were discussed at 28th session in 1989 and at 30th session in 1996.

In 1998, J. Remane, President of the ICS, distributed the last version of the ISC to be discussed in national stratigraphic organizations. The Interdepartmental Stratigraphic Committee of Russia submitted its comments and proposals to the ICS in April 1999. In the ISC version that was circulated at the Brazilian congress many proposals of our committee and other organizations were ignored, and the document appeared to be essentially analogous to the ISC variant of 1998 (Explanatory..., 2000). In spite of the emblems of UNESCO and IUGS, which evidently indicate the high international status of the chart approved, the latter has received an important criticism and even caused the irritation.

The innovations in the ISC can be briefly described as follows:

The Precambrian. The numerical system of subdivision (the boundary ages are determined in rounded values) is actually authorized. Such subdivisions as "Riphean" and "Vendian" are not included. Geochronological subdivisions are established arbitrarily. The Precambrian consists of two eonothems: the Archean with four erathems and the Proterozoic with three erathems and ten systems.

The Paleogene and Neogene systems are considered as independent ones.

New subsystems and series are introduced: two series (Mississippian and Pennsylvanian) in the Carboniferous and three series (Lopingian, Guadalupian, and Cisuralian) in the Permian.

Among new stages that got the official status, there are the Induan and Olenekian in the Triassic; the Asselian, Sakmarian, Artinskian, and Kungurian of the Russian scale are kept for the Lower Permian; Roadian, Wordian and Capitanian stages of the American scale are accepted for the Middle Permian, and Wuchiapingian and Changhsingian stages of China are as subdivisions of the Upper Permian; the new Gelasian Stage is introduced into the Upper Neogene.

Several stages are now abolished: all in the Cambrian, and some in the Ordovician and Silurian.

Boundaries are dated according to recommendations of corresponding subcommissions and to data compiled by G.S. Odin (Explanatory..., 2000).

New symbols are introduced for two systems (ε for the Cambrian and "E" for the Paleogene).

Stages are symbolized by the lowercased initial letter of the system name and by numbers from below upward. For example, stages of the Neogene System (N) are denoted as n_1–n_9 (see the chart below).

System	Series	Stage	Stage symbol
Neogene N	Pliocene N_2	Gelasian	n_9
		Piacenzian	n_8
		Zanclean	n_7
	Miocene N_1	Messinian	n_6
		Tortonian	n_5
		Serravalian	n_4
		Langhian	n_3
		Burdigalian	n_2
		Aquitanian	n_1

In this chart, the letter/number symbols and colors for the units (not always apt, by the way) are as those in the "Geological Atlas of the World".

Two moments are noteworthy. First, stage is the ISC unit of the lowermost rank. Second, the recent activity of the ICS subcommissions was focused on definition of stage boundaries. This has both the positive and, in my opinion, negative aspects.

In 1986, the ICS approved the concept of the Global Stratotype Section and Point (GSSP), according to which every stratigraphic unit of the ISC should be defined by its lower boundary. In this connection, the distinction is made among (1) formal units (lower boundaries of which are defined by the GSSP approved), (2) semiformal units (different versions of their GSSP are under consideration of corresponding working groups), and (3) informal. Among 39 Paleozoic boundaries, 21 are formal, whereas only two (?) of 30 Mesozoic and 8 of 20 Cenozoic boundaries are of the same status. Surprisingly, the Mesozoic always regarded as erathem with most detailed subdivisions turned out to be subdivided, from the formal standpoint, much worse than other erathems.

It should be noted here that the boundary definition must be officially voted by a majority of 60% yeses first in the working group responsible for the boundary definition, then in a concerned ICS subcommission, and, finally, in the ICS (with subsequent publication of results). Regretfully, the voting is formal in some cases, hold in a hurry without comprehensive scientific discussion, and pursuing national or "patriotic" goals.

In opinion of some participants of the congress, the ICS efforts to be concentrated on the GSSP, or "golden spikes," confused the tasks of stratigraphy. Instead of studying stratigraphic units proper, the ICS subcommissions paid main attention to the "spikes", i.e., to the lower boundaries of the units (current practice is exactly like this), thus converting the unit definition into a concept. Many stratigraphers think, however, that such a procedure is nothing else but a technology in terms of really existing stratigraphic concepts (chronostratigraphy, multiple stratigraphy, regional stratigraphy, stratigraphic chronometry). It should be used of course to denote boundaries, but it cannot substitute the historical-geological approach to the problem of subdivision of geological sequences. The devotion to "points" and "spikes" brings nothing to the analysis of stratigraphic units, virtually diminishing and even denying significance of regional stratigraphy for the ICS development.

THE ABRIDGED VERSION OF THE INTERNATIONAL STRATIGRAPHIC GUIDE

The first edition of the International Stratigraphic Guide (ISG) edited by H. Hedberg (USA) was issued in 1976. The second edition (Ed. A. Salvador, USA) came out in 1994. The abridged version of the latter presented at the IGSM (M.Murphy and A. Salvador Eds.) was published in an issue of "Episodes" of 1999. The ICS believes that the abridged version is more accessible (lesser in volume and cheaper) than the full guide and may help unification of stratigraphic classification, terminology, and procedure. The structure of this version is the same as that of the guide, where litho-, bio-, allo-, magneto-, and chronostratigraphy units are distinguished. The editors emphasize that the abridged version represents a recommended approach to stratigraphic investigations rather than the code. In spite of the disputable concept of multiple stratigraphy, the code admits the necessity of utilization of all integrated information obtained by different methods. We wait now for the Russian translation of the code, as it can be helpful for Russian stratigraphers. However, we should not give up the Russian "Stratigraphic Code" to be guided by the international one, where the basic concept is the multiple stratigraphy (in the American interpretation), many principles of which have received criticism. The Russian "Stratigraphic Code" seems to be better worked out.

SOME PROBLEMS OF STRATIGRAPHIC PRACTICE

Different problems of stratigraphy were subjects of discussion at the workshops and meetings of the IGC. The tendency of combining different methods of stratigraphic investigations was particularly stressed. The combination allows us to control results obtained by individual methods and to make necessary corrections. In the last years, traditional methods (bio-, litho-, magnetostratigraphy and others) were supplemented by new ones, e.g., by chemostratigraphy, astronomic and sequence stratigraphy. Possibilities of new methods are frequently exaggerated without due regard for biostratigraphic and radiological methods, which are principal ones (in any case, for the Phanerozoic), because they only are able to get insight into irreversible unidirectional geological processes. For example, it was noted that the popular sequence stratigraphy has a limited scope of employment, inadequately elaborated methodical aspects, and indefinite, unfinished nomenclature. On the contrary, zonal stratigraphy is a solid basis for biostratigraphic subdivision of all systems and stages, and nothing else is comparable with it in trustworthiness and resolution ability. There are about 130 biozones established in the Paleozoic, 145 biozones in the Mesozoic, and 45 biozones in the Cenozoic.

Paleogeographic materials that have been demonstrated at the congress are noteworthy. Paleogeographic data have increasing importance for reconstruction of geological events and geological history. They also facilitate a "transition" to tectonic reconstructions, which can be successful when facts receive an unprejudiced interpretation but are not used to justify certain tectonic models. Great attention was given to 24 paleogeographic maps compiled by working group of "The Peri-Tethys Program". Regretfully, some of the maps are insufficiently reliable.

One report at a workshop of the congress was devoted to perspectives of geological mapping in the XXI century. It was supposed that the geological mapping in its present form would become an anachronism and field works would be reduced. The mapping procedure should be based on the Internet database, remote sensing results and so on, without the obligatory expeditions. Geologists of many countries did not support this idea.

The present state of geology cannot be considered inspiring: geological surveys are reduced, many scientific programs are abolished, and so on. The same is true for stratigraphy, which seems to be ahead of practice requirement, on the one hand, and is frequently substituted by geophysical information in the regional and prospecting works, on the other. Against this background, the state of the Russian stratigraphy looks better. We have many different sections described and immense collections of fossils, we publish respectable monographs and stratigraphic schemes of new generation. However, there are serious defects in our activi-

ties. For example, we do not participate the International Deep Sea Drilling Program thus being deprived of many important materials; our laboratories are insufficiently equipped; few young specialists are trained in geology and stratigraphy, and so on. In the last period, our organizational activity declined. As a result, we are unable effectively influence new ideas and submit our own to the ICS. It should be also stated that Russian scientists feel a certain isolation, having a limited possibility, because of certain ideological tendencies among the ICS authorities, to take part in discussion and solution of important problems (by the way, none of Russian works is cited in "Explanatory note to the International Stratigraphic Chart," although Russia contributed so much to international stratigraphy).

Representation of Russian scientists in the ICS is reduced almost to zero. Among leaders of the Bureau and 18 subcommissions (chairmen and vice-chairmen), there has been only one representative of Russia and now are two (compare to 12 for United States; 5 for each Austria and Italy; 3 for each South Africa, Germany, Great Britain, and France; 2 for each Switzerland, Canada, China, Belgium, and Sweden). This is the situation after a brilliant period of the 1970–1980s, when V.V. Menner was the Russian representative in the IUGS, the President of the ICS, and the Chairman of the Paleogene Subcommission. In addition, we give him credit for his active role as the Chairman of the National Committee of Geologists (NCG) of our country who knew how to be prepared for such important events as the IGC sessions. He organized publication of papers of Soviet geologists, preparation of exhibitions to demonstrate the progress achieved in geology, and delegations of authoritative and active scientists. He thought of strategy in forthcoming discussions, analyzed development of stratigraphy in Russia and other countries, and so on. Regretfully, the NCG, Russian Academy of Sciences, and Ministry of Natural Resources did nothing of this kind before the last congress. There is a hope that the Russian delegation will be prepared better for the next IGC in Florence both organizationally and scientifically.

Finally, the new Bureau of the ICS was elected in Brazil: Chairman Dr. F.M. Gradstain (Norway), 1st Vice Chairman Dr. R.H. Lane, 2nd Vice Chairman Dr. S. Finney, Secretary General Dr. J.G. Ogg (all three from the United States!), Past Chairman Dr. J. Remane (Switzerland).

Major objectives of the ICS for the next four years are to simplify and streamline the ICS subcommission structure, and to increase the relevance and awareness of the ICS work on educational and applied stratigraphy. It was also decided to create a special service for information on stratigraphic code and standards, geological time scale, application of different methods, and so on. In addition, the ICS is obliged to complete a standard geological time scale, to finance stratigraphic projects, and to complete work on GSSPs of stage boundaries (this task should not substitute, however, the real role of stratigraphy in modeling the Earth history).

For the following four-year term Prof. E. De Mulder was elected as the President of the IUGS, Drs. T. Sato (Japan) and P. Bobrowsky (Canada) as Vice-Presidents.

I should remind once again that the IGC sessions are important forums of demonstration of achievements in geology and discussion of new ideas. Exchanging information, geologists learn from each other, and if we are a part of the international scientific community, we must know all current tendencies of the world science.

REFERENCES

Explanatory Note to the International Stratigraphic Chart, Paris: UNESCO, 2000, pp. 1–16.

International Stratigraphic Guide. An Abridged Version, Murphy M.A. and Salvador A., Eds., *Episodes*, 1999, vol. 22, no 4, pp. 255–271.

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